I-5 MP 211.5 Secret Creek (WDFW ID 990622): Preliminary Hydraulic Design Report

Julie Heilman, PE, State Hydraulic Engineer
WSDOT Headquarters Hydraulics Office – FPT20-00157

Tyler Nabours PE, Surface Water Engineer
Parametrix – FPT20-06757

Paul Fendt PE, Senior Engineer
Parametrix – FPT20-22645

Sarah Rife EIT, Geomorphologist and Modeler
Parametrix – FPT20-06054

Steve Krueger, Fisheries Biologist
Parametrix – FPT20-28767

Northbound I-5 Secret Creek – Remove Fish Barrier
MP 211.5 Secret Creek
Preliminary Hydraulic Design Report
December 2021

Americans with Disabilities Act (ADA) Information

Materials can be made available in an alternative format by emailing the WSDOT Diversity/ADA Affairs Team at wsdotada@wsdot.wa.gov or by calling toll free: 855-362-4ADA (4232). Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Title VI Notice to Public

It is Washington State Department of Transportation (WSDOT) policy to ensure that no person shall, on the grounds of race, color, national origin, or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For Title VI complaint forms and advice, please contact OEO's Title VI Coordinator at 360-705-7082 or 509-324-6018.

Contents

Figures

Tables

Acronyms and Abbreviations

ADA – Americans with Disabilities Act

BFW – Bankfull width

cfs – cubic feet per second

Ecology – Washington State Department of Ecology

EPA – Environmental Protection Agency

ESO – Environmental Services Office

FEMA – Federal Emergency Management Agency

FIRM – Flood Insurance Rate Maps

FIS – Flood Insurance Study

FPW – Flood-prone width

FUR – Floodplain utilization ratio

ft – feet

ft/s – feet per second

HSPF – Hydrological Simulation Program Fortran

I-5 – Interstate 5

LWM – large woody material

MP – Milepost

MRI – Mean Recurrence Interval

MWM – Mobile woody material

NB – Northbound

NB I-5 offramp – Northbound Interstate 5 offramp

NEP – National Estuary Protection

NRCS – National Resource Conservation Service

OEO – Office of Equal Opportunity

SB – Southbound

SCD – Snohomish Conservation District

SR – State Route

SWIFD – Statewide integrated fish distribution

TMDL – Total daily maximum load

USGS – United States Geological Survey

WCDGs – Water Crossing Design Guidelines

WDFW – Washington Department of Fish and Wildlife

WDNR – Washington Department of Natural Resources

WRIAs – Water Resource Inventory Areas

WSCC – Washington State Conservation Commission

WSDOT – Washington State Department of Transportation

WWTIT – Western Washington Treaty Indian Tribes

This Page Intentionally Left Blank

1.0 Introduction and Purpose

The Washington State Department of Transportation (WSDOT) proposes a project to provide fish passage at the Northbound (NB) Interstate 5 (I-5) crossing of Secret Creek (Site ID 990622) at Milepost (MP) 211.5. The purpose of this project is to comply with a federal injunction requiring the state of Washington to correct fish barriers in Water Resource Inventory Areas (WRIAs) 1 through 23 (*United States et al. v. Washington et al. No. C70-9213 Subproceeding No. 01-1*, dated March 29, 2013). The existing structure on Northbound (NB) I-5 has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 990622) due to a "water surface drop" resulting in a fish pass-ability of 67 percent. Additionally, the existing pipe is damaged with multiple holes along the invert that cause flow disconnection during lower flows and result in a barrier condition. Once corrected, the potential fish habitat gain is 8,215 meters. This report documents the site and reference reach assessment, geomorphic analysis, hydrologic and hydraulic analyses, fish passage design, streambed material design, and climate change analysis Parametrix performed in coordination with WSDOT Headquarters Hydraulics and the WSDOT Project Office located in Mount Vernon, Washington.

In accordance with the injunction and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) using a full span bridge, or (c) using the stream simulation methodology. Avoidance of the stream crossing was determined not viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT proposes to replace the existing crossing structure with a structure designed using the unconfined bridge design methodology. This method was selected primarily because the floodplain utilization ratio is greater than 3.0 which indicates an unconfined system, and the proposed replacement structure could be up to 255 feet long.

The structure is in Snohomish County, 4 miles north of Arlington, Washington, in WRIA 5. The highway runs southeast to northwest at this location. Secret Creek generally flows northwest to southeast, beginning approximately 3 miles upstream of the NB I-5 crossing (Figure 1, Vicinity Map). The inlet to the NB crossing is 0.4 mile upstream of the Secret Creek confluence with Pilchuck Creek.

The proposed project will replace the existing 8-foot-diameter, 240-foot-long corrugated steel culvert (as provided in survey) with a minimum 40-foot span structure to improve fish passage while providing a safe roadway for the traveling public. It should be noted that the WDFW Level A Culvert Assessment describes this culvert as 8 feet in diameter 309 feet long, and the Fishway Assessment Report describes the culvert as 9.5 feet in diameter and 271 feet long. This report will assume the dimensions provided by site survey. This proposed structure is designed to meet the requirements of the federal injunction using the bridge design methodology outlined in the 2013 Water Crossing Design Guidelines (WCDG) (Barnard et al. 2013). Preliminary hydraulic design reports are being developed for both the NB and Southbound (SB) I-5 crossings of Secret Creek. Due to the proximity and joint hydraulic modeling of these two crossings, portions of this report will include analyses of both crossings

Source: WA DNR, ESRI, WSDOT, Snohomish County

Figure 1.1 Vicinity Map

I-5 Secret Creek

Secret Creek Culverts at I-5

Watercourse

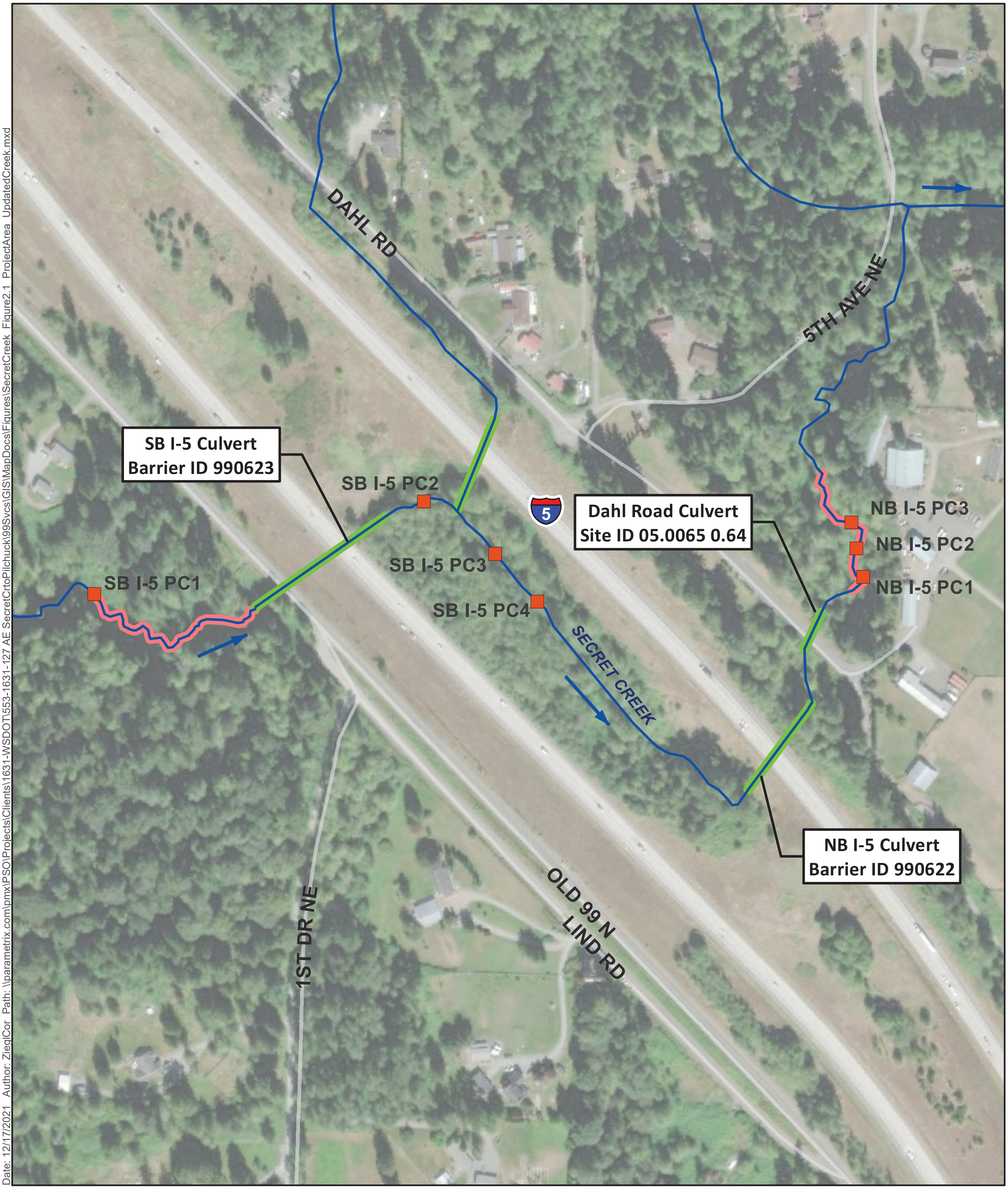
0 750 1,500 3,000 Feet

Snohomish County, WA

2.0 Site Assessment

The primary site investigation was conducted on March 20, 2020, by Parametrix surface water engineers and a fisheries biologist. The team recorded site observations and measurements at the crossings, downstream approximately 500 feet past the Dahl Road Culvert, between the Dahl Road and I-5 NB Culvert, and approximately 200 feet upstream of the I-5 NB culvert inlet. Data collection included site photographs, bankfull width (BFW) measurements, record of large woody material (LWM) in the channel and recruitment potential, pebble counts, fish habitat assessment, record of pool and riffle or step dimensions, if applicable, record of rocks and other key features, and records of overbank vegetation and soil types. To aid in recording the locations of observations, the team extended a tape measure along the stream thalweg, upstream and downstream of both barriers. Figure 2.1 displays the extents of the site investigation, including locations of pebble counts taken and potential reference reaches identified.

Date: 12/17/2021 Author: ZieglCor Path: \\parametrix.com\pmx\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\GIS\MapDocs\Figures\SecretCreek_Figure2.1_ProjectArea_UpdatedCreek.mxd



Source: ESRI, WSDOT, StreamStats, WA DNR, Snohomish County

Figure 2.1 Project Area

Secret Creek I-5

Culvert

Reference Reach

Watercourse

Pebble Count Locations

0 125 250 500 Feet

Snohomish County, WA

The site assessment began at the NB I-5 culvert outlet. The culvert is an 8-foot-diameter, 240-foot-long corrugated structural plate steel pipe. According to the WDFW Culvert Assessment Report, the culvert has 15 metal expansion-ring weirs spaced approximately 18 feet apart (Figure 2.2) and a concrete apron with a v-notch weir at the outlet (Figure 2.3). The bottom of the existing culvert pipe has multiple large holes that create flow disconnection at lower flows and create a barrier condition (WDFW 2018). Approximately 4 feet of scour exist at the culvert outlet. Distances downstream for this reach were measured from the NB I-5 culvert outlet.

Figure 2.2. Inside of NB Culvert, Looking Upstream

Figure 2.3. NB Culvert Outlet, Concrete Apron Weir, Plunge Pool

From 0 to 45 feet downstream of the NB culvert outlet, both the left and the right banks are armored with 24- to 36-inch riprap (Figure 2.4). At 28 feet downstream of the NB culvert outlet, the stream takes a 90-degree bend to the north (Figure 2.5).

Figure 2.4. Riprap on Right Streambank

Figure 2.5. 90-Degree Bend

A series of five log grade control structures are spaced approximately 20 feet apart from 40 to 120 feet downstream (Figure 2.6). Each log is between 12 to 18-inches in diameter and approximately 20-feet long. These logs and the previously mentioned metal weirs inside of the culvert were constructed during 2000 (WDFW 2019). At 135 feet downstream, a 12-inch-diameter by 20-foot-long piece of LWM and a 4-inch-diameter by 20-foot-long piece of LWM was present on the left streambank and over the main channel (Figure 2.7).

Figure 2.6. Log Grade Control

Figure 2.7. LWM, Dahl Road Culvert Inlet

The Dahl Road culvert inlet is 145 feet downstream. It is a squashed CMP culvert with an 8.5-foot span and a 6.5-foot rise and has no slope (Figure 2.8). The reach downstream of the Dahl Road Culvert has five log grade control structures at 20-foot spacing, like the reach upstream of Dahl Road.

Figure 2.8. Dahl Road Culvert Inlet, WDFW ID 05.0065 0.64

Figure 2.9. Log Grade Control, Dahl Road Culvert Outlet

The site assessment crew continued moving downstream in search of a reference reach that resembled a more natural stream morphology with relatively limited evidence of management. A reference reach was identified, which, for purposes of determining average gradient through the reach, begins approximately 85 feet downstream of the Dahl Road culvert outlet and at the downstream of its associated log grade controls, though field measurements did not begin until 150 feet downstream of the Dahl Road culvert outlet. For consistency with the WSDOT Field Report (Appendix A), descriptions of locations along the channel centerline begin relative to a 10-inch-diameter by 30-foot-long piece of LWM located at 150 feet downstream of the Dahl Road culvert outlet. This location was earlier identified during the field assessment as the upstream limit of the reference reach. Between 14 and 41 feet downstream of the 10-inch-diameter by 30-foot long LWM piece, Pebble Count 1 was performed at a riffle section upstream of a beaver dam pool (Figure 2.10). At 44 feet downstream, the stream bends sharply to the left, and a large 16-foot-wide and 3- to 4-foot-deep pool created by a beaver dam is 72 feet downstream (Figure 2.11).

Figure 2.10. Streambed Material at Pebble Count 1

Figure 2.11. Pool Upstream of Beaver Dam

There is an approximately 3-foot high drop from the top of the beaver dam to the downstream plunge pool 89 feet downstream of the beginning of the reference reach. Pebble Count 2 was performed beginning at 112 feet downstream (Figure 2.12). Several BFW measurements were taken in this area; a measurement of 11 feet was taken at 105 feet downstream, a measurement of 8 feet was taken at 119 feet downstream (Figure 2.13), and a measurement of 10.2 feet was taken at 127 feet downstream. Some locations along the streambanks exhibit undercutting.

Figure 2.12. Streambed Material at Pebble Count 2

Figure 2.13. 8-foot BFW, 119 Feet Downstream

A 12-inch-diameter, 30-foot-long log spans the channel approximately 3 feet above the water surface at 146 feet downstream (Figure 2.14). At 174 feet downstream, an 8-inch-diameter by 20-foot-long log protrudes into the channel from the left bank (Figure 2.15).

Figure 2.14. 12-inch-diameter, 30-foot-long LWM at 146 Feet Downstream

Figure 2.15. 8-inch-diameter, 20-foot-long LWM at 174 Feet Downstream

At 173 feet, the stream widens into a shallow pool. The BFW measured 15 feet here (Figure 2.16). A large 24-inch-diameter tree is present on the right bank, and it hangs above this pool at close to a 45-degree angle. LWM and other debris have jammed on the right bank of this pool area (Figure 2.17).

Figure 2.16. 15-foot BFW, Pool at 173 to 186 Feet Downstream

Figure 2.17. LWM Jam on the Right Bank at 186 Feet Downstream

Another log jam of LWM and mobile woody material was encountered at 195 feet downstream. LWM including an 8-inch-diameter, 10-foot-long log and a 10-inch-diameter, 25-foot-long log is present in this jam (Figure 2.18). Pebble Count 3 was performed at 204 feet downstream (Figure 2.19).

Figure 2.18. LWM at 195 Feet Downstream

Figure 2.19. Streambed Material at Pebble Count 3

At 204 feet downstream, the stream bends to the right, and a pool has formed between 204 and 216 feet downstream on the left bank (Figure 2.20). A BFW measurement of 13.9 feet was taken at 229 feet downstream (Figure 2.21). Tree cover overhangs the stream from the left bank along this bend.

Figure 2.20. Corner Pool on the Left Bank at 204 to 216 Feet Downstream

Figure 2.21. 13.9-foot BFW, 229 Feet Downstream

A bankfull width measurement of 13.7 feet was taken at 253 feet downstream (Figure 2.22). A 24-inch-wide, 12-foot-long log is present 261 feet downstream, protruding into the stream from the left bank. This log forces water towards the right bank, leading to the formation of a lateral scour pool and gravel bar (Figure 2.23).

Figure 2.22. 13.7-foot BFW, 253 Feet Downstream, Looking Upstream

Figure 2.23. LWM at 261 Feet downstream, Lateral Scour Pool and Gravel Bar

At 289 feet downstream, a 10-inch-diameter, 15-foot-long log acts as a weir creating a plunge pool (Figure 2.24). At 306 feet downstream, two 3.5-foot-diameter boulders are present on the right bank partially embedded within a gravel bar.

Figure 2.24. 10-inch-diameter, 15-foot-long Channel Spanning LWM at 289 Feet Downstream

Figure 2.25. Two 3.5-foot-diameter Boulders on the Right Bank at 306 Feet Downstream

At this point in the assessment, the field team ended the reference reach assessment and moved to the reach upstream of the NB I-5 culvert in the median between the NB and SB lanes of I-5.

For the assessment of the reach upstream of the NB I-5 culvert, distances were measured from the culvert inlet (Figure 2.26). The stream takes a sharp, 90-degree turn to the left as it enters the culvert. The inlet to the NB I-5 culvert is formed by a half-pipe CMP supporting the invert of the channel, and a concrete reinforcement wall supports the half-pipe. Immediately upstream of the half-pipe, the channel is protected by large boulder armoring that forms the channel substrate and banks (Figure 2.27). The presence of this material continues throughout the reach.

Figure 2.26. I-5 NB Culvert Inlet, WDFW ID 990622

Figure 2.27. Boulder Armoring on the Right Bank Upstream of Culvert Inlet

The boulders along the right bank at the bend can be seen in Figure 2.28. Five pieces of LWM were observed in a jam at 40 feet upstream with diameters between 8 inches and 30 inches, and lengths ranging from 20 to 50 feet (Figure 2.29). A BFW measurement of 8.5 feet was taken at 40 feet upstream (Figure 2.29).

Figure 2.28. Boulder Armoring on Right Bank at 90-degree Bend

Figure 2.29. 8.5-foot BFW, 5 Pieces of LWM at 40 Feet Upstream

The stream is significantly more confined upstream of the NB I-5 culvert compared to the reference reach. The channel also lacks the sinuosity and floodplain benching that were present in the reference downstream. A cemented streambed substrate was noted at 175 feet upstream. A BFW measurement of 9.5 feet was taken at 110 feet upstream (Figure 2.30). A BFW measurement of 9.9 feet was taken at 225-feet upstream (Figure 2.31).

Figure 2.30. 9.5-foot BFW, 110 Feet Upstream

Figure 2.31. 9.9-foot BFW, 225 Feet Upstream

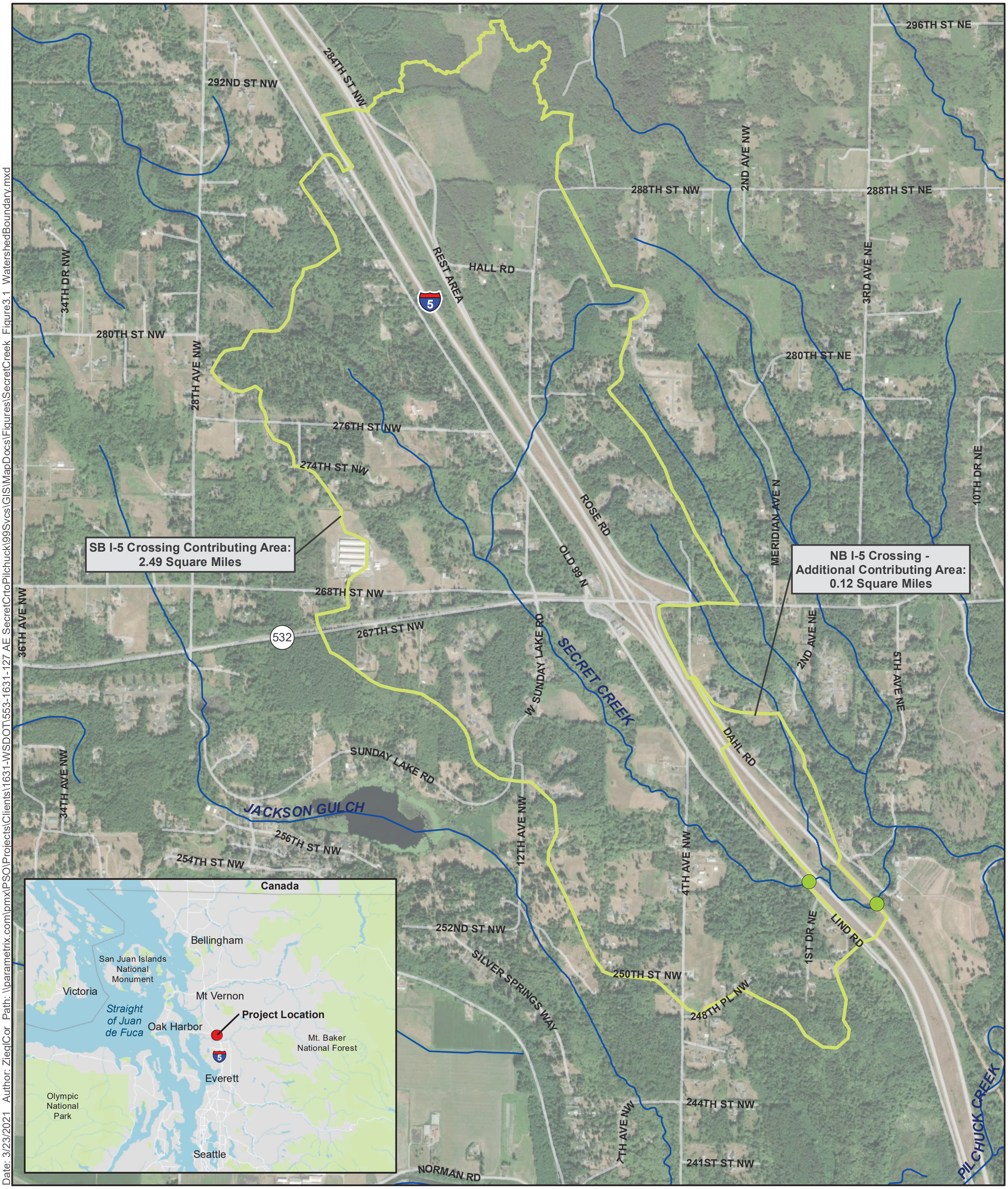
3.0 Watershed Assessment

3.1 Watershed and Landcover

The contributing watershed basin to the NB I-5 crossing of Secret Creek was first obtained using the United States Geological Survey (USGS) StreamStats delineation tool. The delineations were then verified and modified where necessary using 2017 LiDAR data captured by Quantum Spatial, provided by the Washington Department of Natural Resources (WDNR) (Quantum Spatial, 2017). The drainage basin comprises an area of 2.61 square miles or 1,673 acres (USGS). Of this 2.61 square miles, 2.49 square miles flow to the NB I-5 crossing via the SB I-5 crossing culvert. The remaining 0.12 square mile of the drainage basin flows to the NB I-5 crossing via an unnamed tributary to Secret Creek. This unnamed tributary collects runoff from I-5 and the adjacent area along the east side of I-5. The unnamed tributary crosses NB I-5 via a 3-foot-diameter corrugated steel culvert pipe (Site ID 996069). The highest elevation in the watershed reaches approximately 495 feet, and the elevation of the channel at the NB I-5 crossing is approximately 97 feet (NAVD88).

Tributaries to Secret Creek begin in the northwest and northeast portions of the watershed, approximately 3 miles from the NB I-5 crossing. The creek generally flows northwest to southeast beginning 0.25 mile north of 276th Street NW. The watershed landcover in the upper western portion of the watershed consists primarily of forest and pasture, while the land cover in the eastern portion of the watershed has a greater degree of developed impervious area from I-5. Land cover types were manually delineated in GIS using ESRI World Imagery (ESRI 2019). The watershed consists of forest (49.9 percent), grass (35.9 percent), impervious area (9.6 percent), and wetland (4.6 percent). Figure 3.1 depicts the watershed boundary.

According to Snohomish County zoning, the watershed is designated primarily as Rural 5-Acre (95.1 percent), which serves to maintain rural character in areas that lack urban services (Snohomish County 2020). The remainder consists of Rural Freeway Service (2.3 percent), Forestry (1.9 percent), and tribal land (0.7 percent).



Source: Snohomish County, ESRI, WSDOT, StreamStats

Figure 3.1 Watershed Boundary

I-5 Secret Creek

Secret Creek Culverts at I-5

Watercourse

Secret Creek Watershed Boundary

0 750 1,500 3,000 Feet

Snohomish County, WA

3.2 Mapped Floodplains

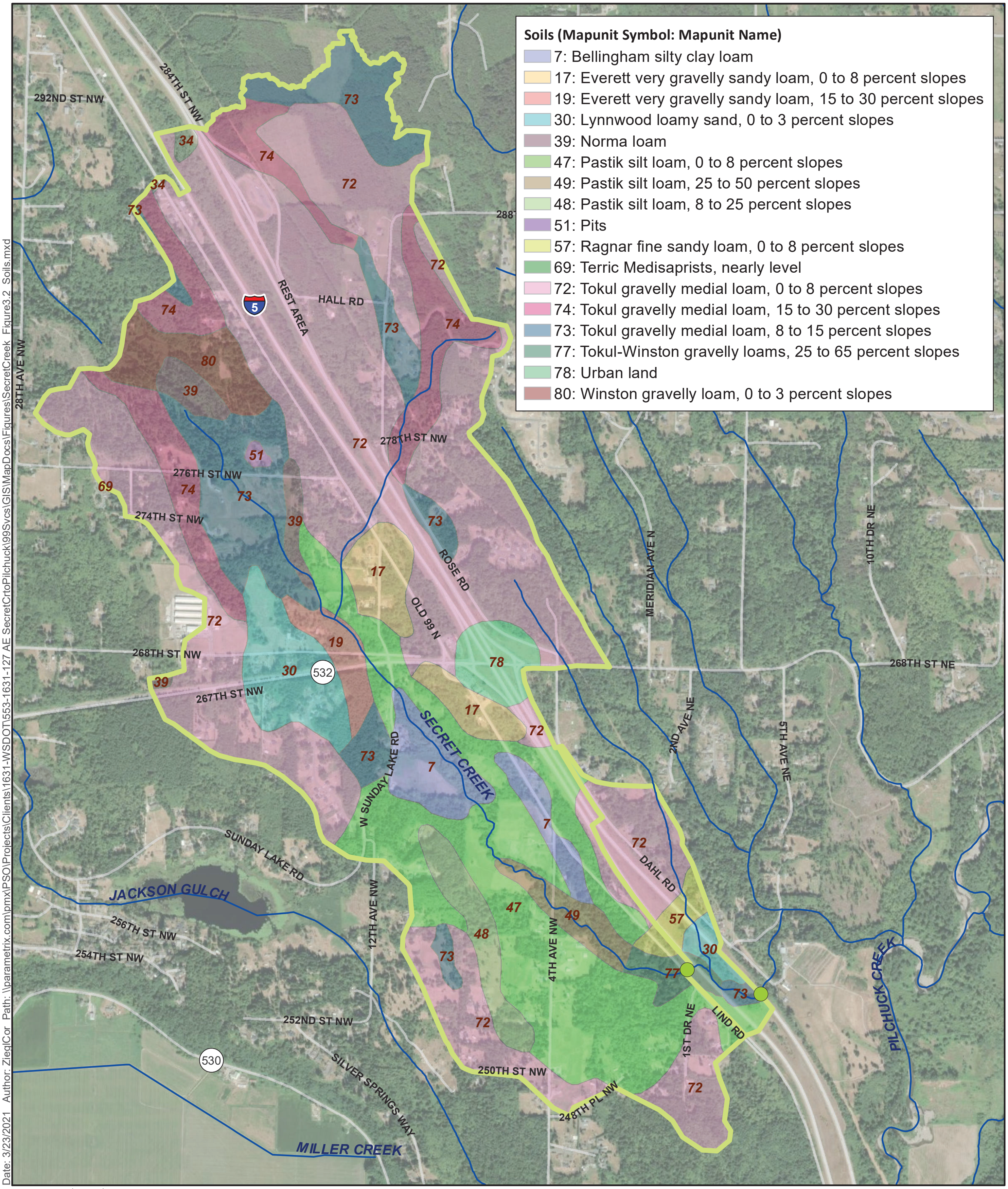
Flood Insurance Rate Maps (FIRM) showing floodplain mapping as established by the Federal Emergency Management Agency (FEMA) were reviewed for the project location. This project is not within a mapped floodplain.

The project is within an area identified as Zone X on the FIRM Number 53061C0380E (Appendix B). This zoning is associated with flood mapping of Pilchuck Creek and this indicates that the project area is determined to be outside of the 500-year floodplain of Pilchuck Creek (FEMA 1999).

3.3 Geology & Soils

The surficial geology of the Secret Creek watershed consists mainly of deposits from the Vashon Glaciation between 19,000 and 16,000 years before the present. Most of the watershed (78 percent) is underlain with Vashon Till (geologic unit Qvt) (Pessl et al. 1989). This material contains poorly sorted rock fragments that are firmly embedded in a matrix of finer components including silt, sand, and clay in variable amounts. This geologic unit is mainly found in the outer reaches of the watershed. The surficial geology of the stream corridor consists of advance outwash deposits from the Vashon glacier meltwater (geologic unit Qva). This material mainly consists of sand, gravel, silt, and clay, and it covers 13 percent of the watershed. The remaining 10 percent of the watershed is recessional-continental deposits (geologic unit Qvrc) consisting of sand, gravel, and silt.

The watershed-specific soils were identified using the National Resource Conservation Service (NRCS) Soil Survey Geographic Database. A graphic representation of the findings is presented in Figure 3.2. The watershed is mainly composed of Tokul Gravelly Medial Loam (63.1 percent) and Pastik Silt Loam (19.4 percent), with the remainder consisting of various sandy and silty loams (NRCS). Tokul Gravelly Medial Loam is prominent in the northern part of the watershed, and it resembles a dark brown gravelly loam with a depth to hardpan ranging from 20 to 40 inches. It is of moderately well drained class above the hardpan layer, and it has poor permeability through the hardpan. This soil has a moderate capacity for water storage and is classified in hydrologic soil group B. Pastik silt loam is prominent in the southern portion of the watershed, and it consists of ashy and regular silt loam. The silty loam is of poorly drained class, has a high capacity for water storage, and is categorized in hydrologic soil group C. Figure 3.2 depicts the watershed soil types.



Source: Snohomish County, ESRI, WSDOT, SSURGO Soils Database, StreamStats

Secret Creek Culverts at I-5
Watercourse
Secret Creek Drainage Basin

0 750 1,500 3,000 Feet

Figure 3.2 Soils
I-5 Secret Creek

Snohomish County, WA

3.4 Geomorphology

3.4.1 Channel Geometry

The channel geometry of Secret Creek was evaluated upstream and downstream of the I-5 crossings using both the DNR-sourced LiDAR topography produced in 2017 and the surfaces created from the WSDOT and Parametrix site surveys. Two site surveys were performed, one for the NB I-5 crossing that Parametrix performed in November 2019 and one that WSDOT performed for the SB I-5 crossing in July 2019. Field observations recorded during the site visit on March 20, 2020, were used to further evaluate the channel geometry. The channel profile, cross-section geometry, and planform are discussed in that order in the following section.

Upstream and downstream profile gradients were assessed using 2017 LiDAR data to provide an understanding of the overall longitudinal profile of the stream outside the vicinity of the I-5 crossings. The profile begins at the downstream confluence of Secret Creek and an unnamed tributary to Pilchuck Creek, and it ends at approximately 2,760 feet upstream of the inlet to the SB I-5 culvert inlet. The channel gradient is approximately 1.53 percent for 1,150 feet between the downstream confluence and Dahl Road. The channel gradient is approximately 2.85 percent for 102 feet between Dahl Road and NB I-5. The reach between Dahl Road and NB I-5 has been retrofitted with a series of five log grade control structures. The channel gradient is approximately 1.25 percent for the 1,150 feet between NB and SB I-5. The channel gradient is approximately 1.11 percent for the 2,760 feet upstream of the SB I-5 culvert. Figure 3.3 depicts the LiDAR longitudinal profile.

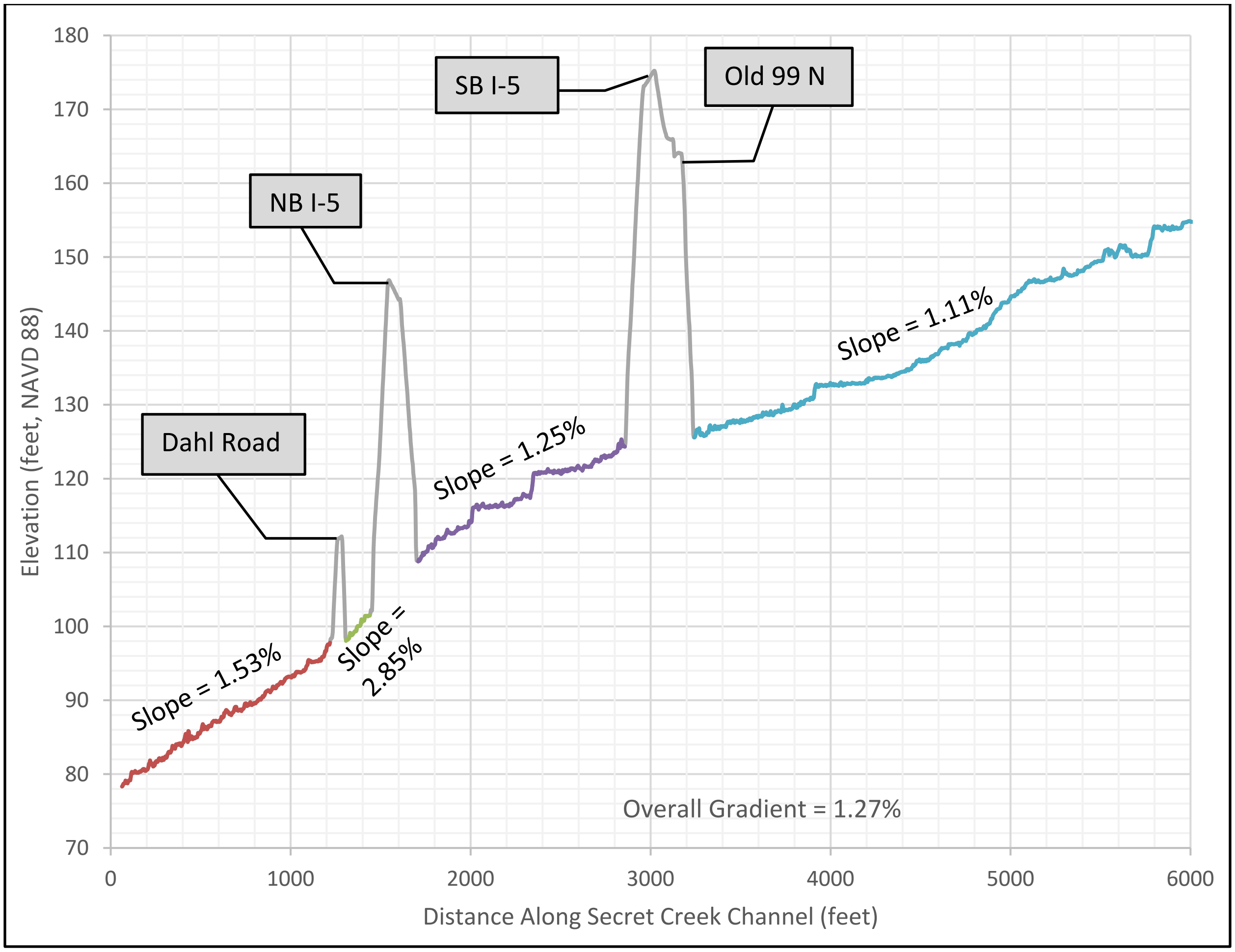


Figure 3.3. Longitudinal Profile of Secret Creek (LiDAR)

Upstream and downstream channel gradients were also assessed using WSDOT and Parametrix site survey data, which provide a more detailed and current understanding of the longitudinal profile of the stream in the immediate vicinity of the I-5 crossings. The surveyed profile begins approximately 212 feet downstream of the Dahl Road culvert outlet and ends at approximately 208 feet upstream of the inlet to the SB I-5 culvert inlet. The channel gradient is approximately 1.30 percent for the 125 feet of channel between the downstream survey limit and the most downstream log grade control structure below the Dahl Road culvert, and is a part the reference reach for purposes of assessing existing channel gradient. Survey indicates that the channel gradient through a series of five log grade controls downstream of Dahl Road is an average of 7.20 percent as measured from upstream to downstream log grade controls, or 3.36 percent measured between the most downstream log grade control and the outlet of the Dahl Road culvert. The channel gradient is approximately 2.29 percent for the 145 feet of channel between Dahl Road and NB I-5. This reach has also been retrofitted with a series of five log grade control structures to help stabilize the steep grade in this section. The channel gradient is approximately 1.26 percent for the 1,170 feet between NB and SB I-5. The channel gradient is approximately 0.59 percent for the 208 feet upstream of the SB I-5 culvert. According to the WSDOT survey, the NB I-5 culvert has a slope of 2.77 percent, and the SB I-5 culvert has a slope of 0.64 percent. The culvert beneath Dahl Road has no slope. Figure 3.4 depicts the WSDOT Survey longitudinal profile.

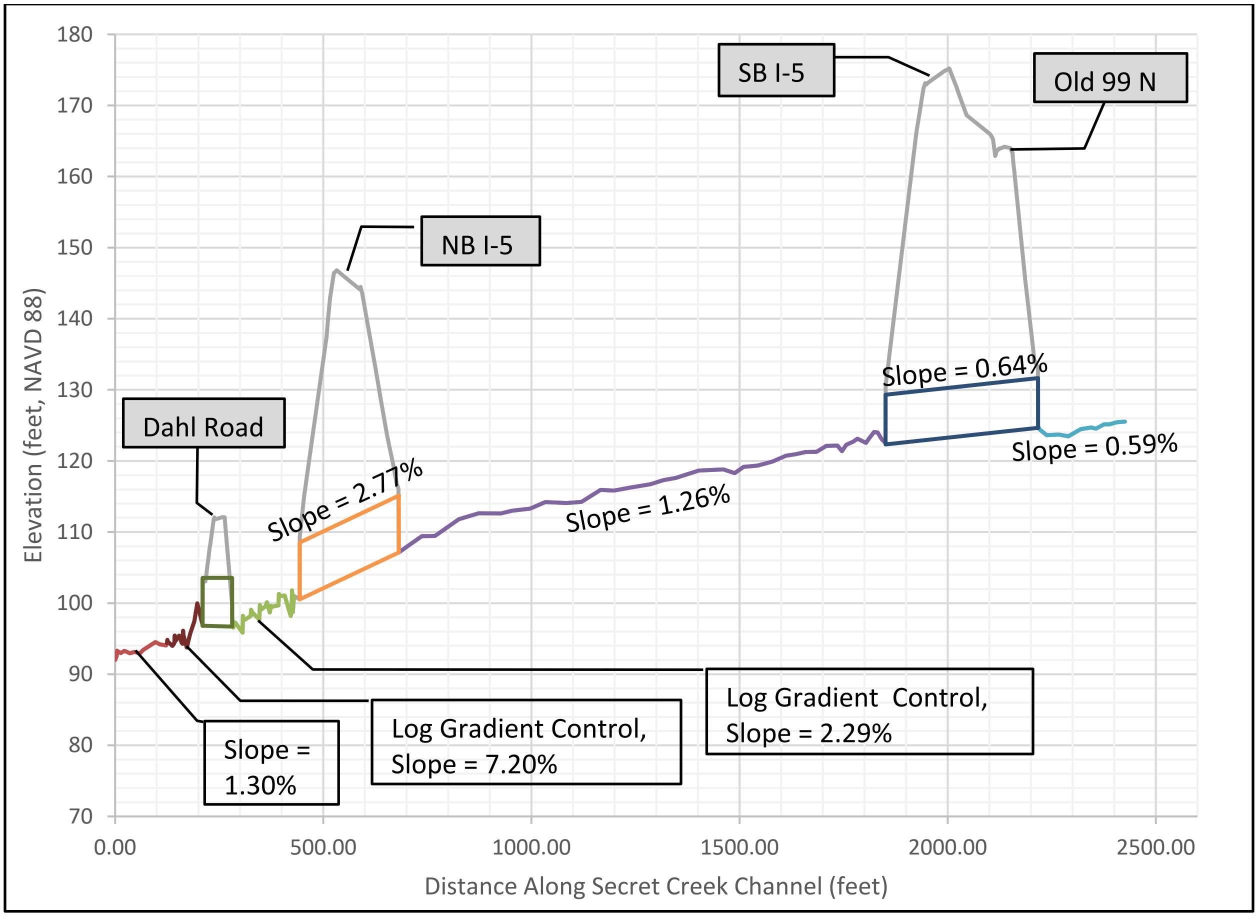


Figure 3.4. Longitudinal Profile of Secret Creek (WSDOT Survey)

The average BFW is 12.0 feet, as obtained during the March 20th, 2020, site visit. Six BFW measurements were taken in the reference reach downstream of Dahl Road; they varied between 8 and 15 feet.

The cross-sectional geometry of Secret Creek varies depending on location. Analysis of cross-sectional geometry will be performed for each of the four distinct reaches in this order: 1) downstream of Dahl Road, 2) between Dahl Road and NB I-5, 3) between NB and SB I-5, and 4) and upstream of SB I-5. This analysis was primarily performed using WSDOT survey data and LiDAR where survey data were not available.

The reach downstream of Dahl Road extends from the downstream end of the Dahl Road culvert to just upstream of culvert Site ID 991975, which is just upstream of the confluence between Secret Creek and the unnamed tributary to Pilchuck Creek. A portion of this reach from 85 feet to 500 feet downstream of the Dahl Road culvert outlet was identified as a reference reach for the NB I-5 crossing. Here, Secret Creek is confined within a low-relief valley, with a top width of approximately 280 feet at the downstream end of the reach and 210 feet at the upstream end. Valley depth from crest to trough varies from approximately 50 feet at the downstream end of the reach to 35 feet at the upstream end. The main channel is set within a flat, well-defined floodplain that modeling indicates becomes engaged during two-year flow events in many areas. Evidence of active side channels was also observed at locations downstream of the installed log grade control structures and upstream of the reference reach. The flood-prone width (FPW), measured as the 100-year flow width from the existing conditions model, varies between 48 and 62 feet, with a reach average value of 56.7 feet, which also well represents the average valley bottom width. See Section 7.0 for additional model discussion. The floodplain utilization ratio (FUR) is defined as the FPW divided by the BFW, resulting in a FUR of 4.7 for this reach. Since the FUR for this reach is greater than 3.0, this reach is considered unconfined. Bankfull depth measurements varied between 1 foot and 2 feet at locations of BFW measurement through the reference reach.

In the short reach between Dahl Road and NB I-5, the confining valley becomes narrower and shallower, with a top width of 170 feet and a depth of 30 feet. The main channel becomes significantly wider and deeper compared to the downstream reach. The 100-year flow is mostly contained within the main channel, and it does not significantly engage the floodplain, resulting in an FPW of 32.3 feet. Using the average BFW of 12.0 feet, this results in a FUR of 2.7, suggesting that the channel is confined in this reach. The confined nature of this channel is due to encroachment caused by the construction of the I-5 and Dahl Road embankments, as well as the channel widening that resulted from the installation of five log-grade control structures in this reach, as discussed in Section 2.0. This encroachment by roadway embankment and main channel widening leads to less floodplain activation, resulting in a narrower FPW and a lower FUR relative to the other stream reaches.

In the reach between the NB and SB I-5 culverts, the valley is deeper and more constrained relative to downstream of Dahl Road. The main channel runs along the east side of the valley, along the toe of the embankment of the NB I-5 lanes. This embankment has a steep and continuous slope up to the roadway of 2(H): 2.5(V). The channel has a trapezoidal shape with no well-defined floodplain in this reach, and it is armored in large riprap material. Near the NB I-5 crossing, the valley is the deepest and most narrow. At 300 feet upstream of the NB I-5 crossing, the channel exhibits an FPW of 28.0 feet and a FUR of 2.3. Moving upstream from the NB I-5 crossing, the embankment slopes lessen as the streambed elevation increases, decreasing the separation between the streambed and the I-5 roadway surface. At 800 feet upstream of the NB I-5 crossing, the channel exhibits an FPW of 61.8 feet and a FUR of 5.1.

In the reach upstream of the SB I-5 culvert, the valley and channel geometry more closely resemble the reach downstream of Dahl Road. The confining valley is 40 to 50 feet deep, and it has a 250-foot top width, with a well-defined floodplain and main channel. Here, BFW measurements averaged approximately 12.1 feet, like the reference reach identified downstream of Dahl Road. Bankfull depths measured between 3 and 3.5 feet in this reach, which results in a BFW-to-depth ratio of approximately 4. This ratio is lower than in the downstream reference reach. The channel geometry appears to have been influenced by historical beaver activity. Evidence of relic beaver dams with upstream sedimentation were observed during the visit with stakeholders, and this activity may have influenced the low BFW-to-depth ratio observed here. Modeling of this reach indicates the observed geometry has not resulted in a disconnected floodplain, with two-year water surface elevations matching the main channel breakover and flows over the two-year event reaching into the floodplain in many areas. This reach has an average FPW of 71.8 feet, resulting in a FUR of 6.0, suggesting that the channel is unconfined. Figure 3.5 shows existing channel cross-sections taken in the reference reach downstream of NB I-5 and Dahl Road as well as in the median between NB and SB I-5.

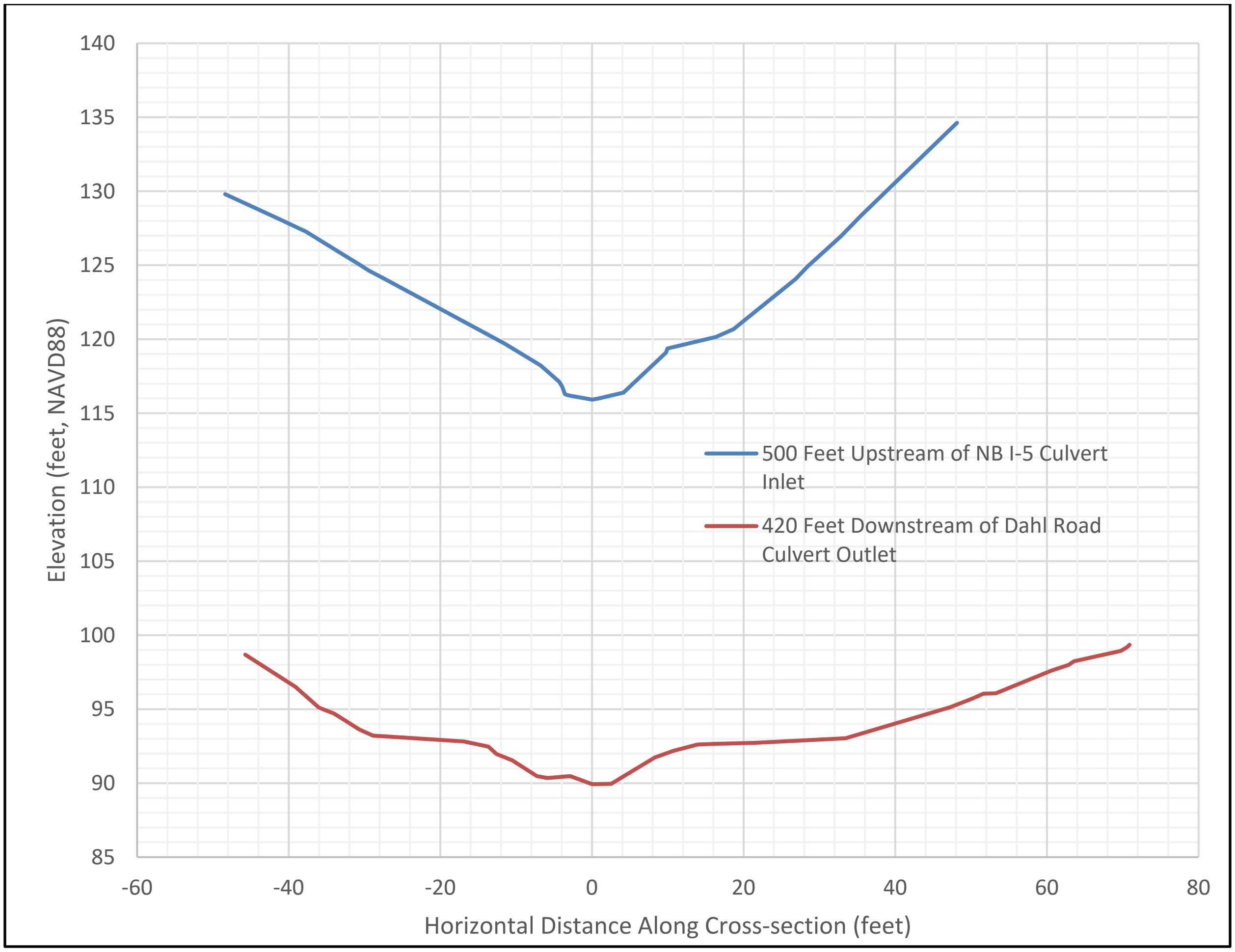


Figure 3.5. Existing Cross-sections Upstream and Downstream of the Existing NB I-5 Culvert

The planform of Secret Creek in between the I-5 crossings and near the NB I-5 crossing is generally straight and follows the centerline of the confining valley. This is due to the construction of roadway embankments and channel modifications protected by riprap armoring, as seen in the reach between NB and SB I-5, and the installation of log-grade controls between the NB I-5 and Dahl Road culverts and within 150 feet downstream of the Dahl Road culverts. Secret Creek takes a 90-degree bend as it exits the SB I-5 culvert, and another as it enters the NB I-5 culvert, but these bends are artificial, and they are reinforced with armored banks.

Upstream of SB I-5 and downstream of Dahl Road, Secret Creek is sinuous. Sinuosity, approximate average meander radii, and approximate average meander belt width measurements were made at the reference reaches upstream of the SB I-5 crossing and downstream of the Dahl Road crossing. These planform measurements were performed in MicroStation using land survey and LiDAR data, and they formed the basis for the proposed planform and are presented in Section 9.

3.4.2 Potential for Aggradation, Incision and Headcutting

As seen in the longitudinal profile, Figure 3.4, the stream gradient in the reach between Dahl Road and NB I-5 is 2.29 percent and the slope of the NB I-5 culvert is 2.77 percent. Both the culvert and downstream reach are steeper than the 1.30 percent and 1.26 percent gradients downstream of the

Dahl Road/log grade controls and upstream of the NB I-5 culvert respectively. The presence of the culvert and log grade control structures immediately downstream have stabilized the stream profile, preventing further degradation and a headcut or knickpoint from migrating upstream.

Removing the culvert and log grade controls without adjustment to the channel profile would create a risk that the streambed material within the crossing would mobilize at a higher rate than material supplied from upstream, which could lead to degradation that results in the formation of a headcut or drop. There is also a risk that a headcut or incision would migrate upstream.

The proposed design includes significant channel grading including a new profile that provides a more consistent channel gradient from upstream to downstream of I-5. The design provides a significant amount of cut in the channel corridor through the area between NB and SB I-5 during construction that will lower the rate and magnitude of potential channel degradation following construction. The design also removes large riprap armoring and cemented stream substrate present in portions of the reach upstream of the NB I-5 culvert.

The proposed average gradient of 1.37 percent is still greater than the existing channel gradient upstream of the SB I-5 crossing. This relative difference does suggest the potential for channel degradation and possible knickpoint migration upstream of the project due to greater mobilization of streambed material in the steeper proposed reach in relation to the existing upstream channel gradient. LWM will be selectively placed in the proposed reach to encourage streambed stability.

The watershed has a moderate sediment supply. Evidence of moderate channel migration was observed during the site visit; see Section 3.4.4 for additional detail. As the channel continues to meander within its floodplain, sediment pulses may be encountered as channel avulsions lead to erosion. It is not anticipated that this moderate sediment supply will have a significant effect on aggradation, incision, or headcutting.

3.4.3 Floodplain Flow Paths

No well-defined floodplain exists for Secret Creek between NB I-5, SB I-5, and the Dahl Road culverts. Downstream of the Dahl Road culvert, flooding actively engages floodplains, and it is contained within the valley walls. The presence of the existing I-5 and Dahl Road embankments disconnect the channel floodplain flow paths upstream and downstream of the crossings.

3.4.4 Channel Migration

Evidence of channel migration including gravel bars, streambank erosion and undercutting, alternate high-flow channels, and meander bends were observed during the site visit. Channel migration is likely to occur over time and limited to within the existing floodplain. Lateral migration is unlikely to result in significant expansion of the floodplain due to the confinement of the valley walls.

3.4.5 Existing LWM and Potential for Recruitment

LWM was documented throughout all reaches of Secret Creek during the site visit. The stream corridor of Secret Creek is heavily wooded, and there is a significant potential for additional recruitment of LWM.

In the reach between the NB and SB I-5 culverts, the LWM encountered was channel-spanning, and trees in this reach are primarily deciduous species. These species include red alder, black cottonwood, cascara, mountain ash, Pacific willow, and big-leaf maple. Downstream of the Dahl Road Culvert, LWM was present, both in-channel and channel spanning. Tree species are still predominantly deciduous in this reach, but coniferous species were also present.

Large riprap and boulders were also noted throughout the site visit, especially between the NB and the SB I-5 crossings (Figure 2.29). Naturally occurring boulders were less frequent, though two large boulders were noted during the site assessment in the reference reach (Figure 2.25). Due to their size, these boulders are not likely a product of fluvial transport but are likely the result of lag deposit from valley downcutting.

3.4.6 Sediment Size Distribution

To evaluate the sediment size distribution for the NB I-5 crossing of Secret Creek, three Wolman pebble counts were conducted downstream of the Dahl Road culvert following standard Wolman pebble count procedures (USDA 2001). Figure 2.1 depicts the locations of the pebble counts downstream of Dahl Road. Figure 3.6 depicts the results of pebble counts performed for the NB I-5 and SB I-5 crossings. Table 3.3 shows the sediment properties of the NB I-5 pebble counts. Photographs of the streambed material of Pebble Count 1, Pebble Count 2, and Pebble Count 3 are depicted in Figure 3.8, Figure 3.9, and Figure 3.10, respectively.

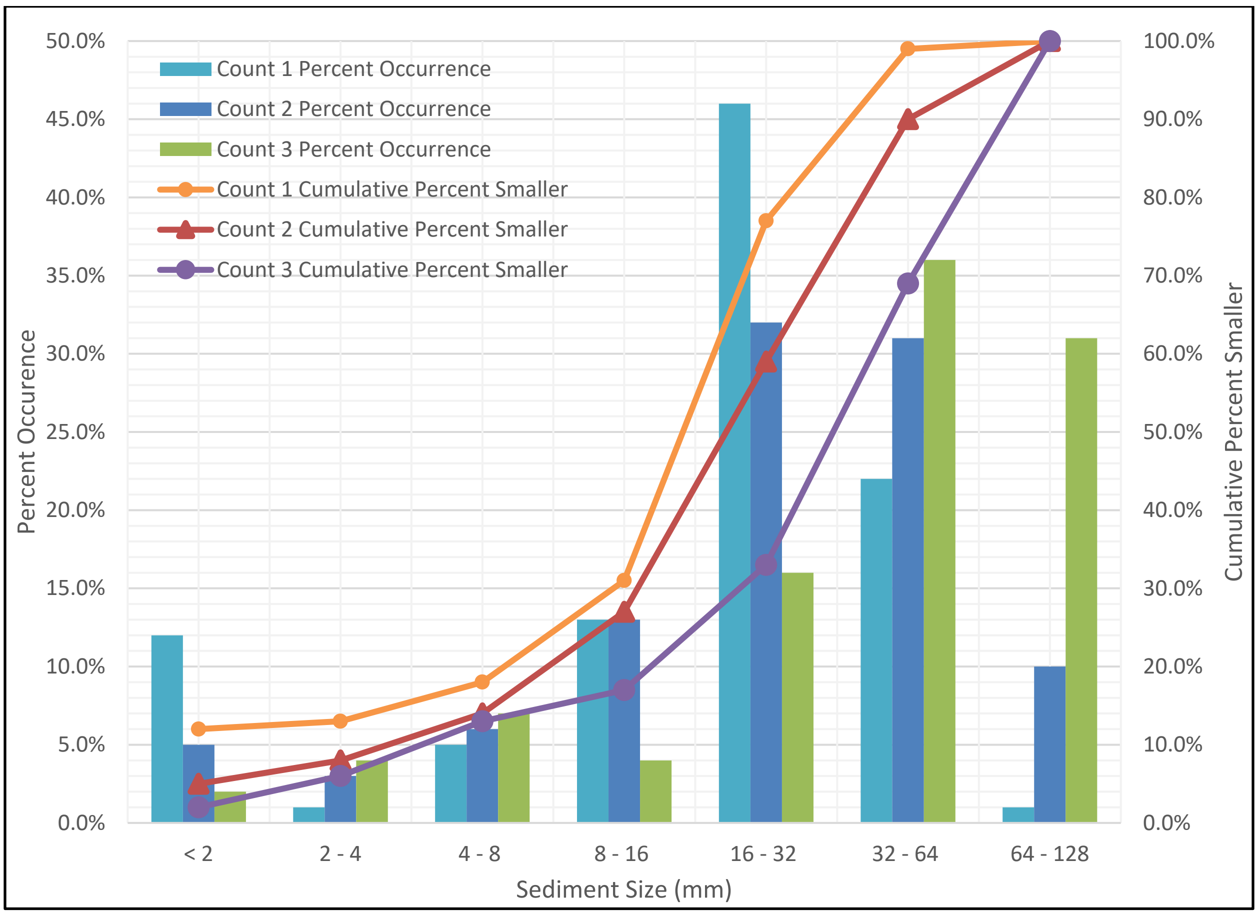


Figure 3.6. Pebble Count Results

Table 3.3. Sediment Properties of Pebble Counts

	Pebble Count 1 Diameter (mm) (in)	Pebble Count 2 Diameter (mm) (in)	Pebble Count 3 Diameter (mm) (in)
D_{16}	6.4 (0.25)	9.2 (0.36)	14.0 (0.55)
D_{50}	22.6 (0.89)	27.5 (1.08)	47.1 (1.85)
D_{84}	42.2 (1.66)	57.8 (2.28)	95.0 (3.74)
D_{100}	70.0 (2.76)	120.0 (4.72)	128.0 (5.04)

Pebble Count 1 was taken approximately 14 to 41 feet downstream of the beginning of the reference reach, shown in Figure 3.9. The Wolman analysis results show that the streambed material is primarily composed of coarse gravel (68 percent of the total), medium gravel (13 percent of the total), sand (12 percent of total), and fine gravel (6 percent of total).

Figure 3.7. Pebble Count 1 at 14 to 41 Feet Downstream of the Beginning of the Reference Reach

Pebble Count 2 was taken approximately 112 feet downstream of the beginning of the reference reach, shown in Figure 3.7. The Wolman analysis results show that the streambed material is composed of coarse gravel (63 percent of the total), medium gravel (13 percent of the total), cobbles (10 percent of total), and fine gravel (9 percent of total).

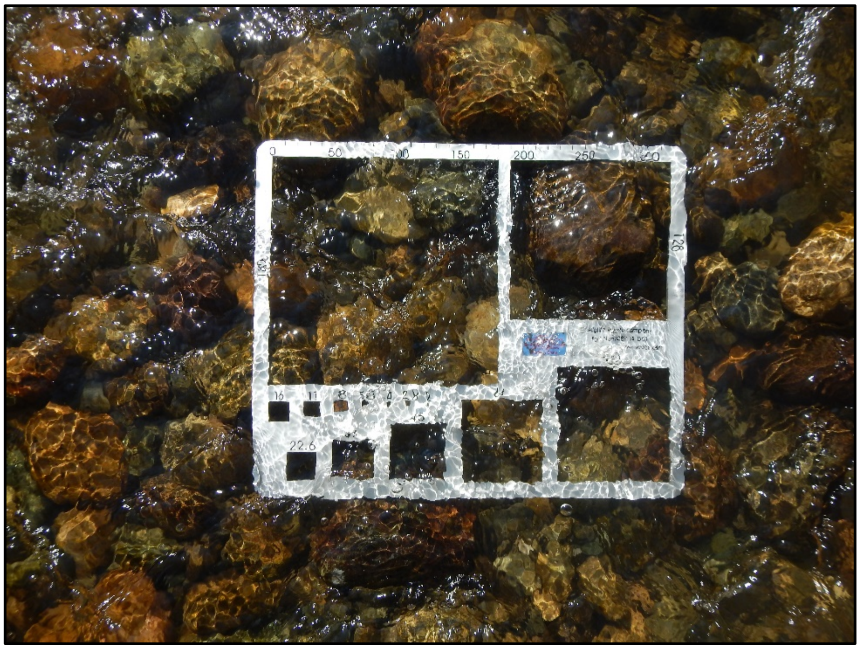


Figure 3.8. Pebble Count 2 at 112 Feet Downstream of the Beginning of the Reference Reach

Pebble Count 3 was taken approximately 204 feet downstream of the beginning of the reference reach, shown in Figure 3.8. The Wolman analysis results show that the streambed material is composed of coarse gravel (52 percent of the total), cobbles (31 percent of total), fine gravel (11 percent of the total), and medium gravel (4 percent of total).

Figure 3.9. Pebble Count 3 at 204 Feet Downstream of the Beginning of the Reference Reach

3.5 Groundwater

No evidence of groundwater impact was noted during the site visit, though the presence of and impacts on construction should be investigated by geotechnical engineers as the design progresses.

4.0 Fish Resources and Site Habitat Assessment

4.1 Fish Use

Native fish potentially found in the project area include chum salmon, coho salmon, sea-run and resident coastal cutthroat trout, resident rainbow trout, and steelhead, Of these, steelhead trout are threatened species under the Endangered Species Act of 1973. In Washington, chum salmon, coho salmon, sea-run and resident coastal cutthroat trout, resident rainbow trout, and steelhead are on WDFW's Priority Habitats and Species List (WDFW 2008).

The statewide integrated fish distribution (SWIFD) webmap identifies the reach upstream and downstream of the culvert as spawning habitat for coho salmon (SWIFD 2020). Steelhead have been documented upstream to the NB I-5 crossing, and upstream areas are identified as gradient accessible to steelhead (SWIFD 2020). Chum salmon have been observed in the lower reaches downstream of I-5, but habitats through the subject culvert and upstream are identified as gradient accessible to chum salmon (SWIFD 2020). SWIFD indicates that resident rainbow trout have not been documented as occurring within Secret Creek; however, they have been documented in the mainstem Pilchuck Creek and the mainstem Stillaguamish River. Therefore, it is likely that resident rainbow trout could be present in Secret Creek. Resident rainbow trout are more prevalent upstream in the North and South Fork Stillaguamish River and its tributaries, while cutthroat trout are more prevalent in the lower mainstem Stillaguamish and its tributaries (WSCC 1999). Coastal cutthroat trout are presumed to be present throughout all accessible reaches of Secret Creek. Both juvenile coho salmon and cutthroat trout were observed while conducting field surveys for this project.

Coho typically begin their upstream migrations in the Stillaguamish River system in September and October, and they generally spawn from mid-November through January (WDFW and Western Washington Treaty Indian Tribes [WWTIT] 1992). Coho fry emerge in March and April, and they spend a full year rearing in the watershed before migrating to the marine waters of Puget Sound (Miller and Somers 1989). Outmigration of smolts typically occurs between mid-March and the end of June (Washington State Conservation Commission [WSCC] 1999).

Chum salmon begin their upstream migrations in the Stillaguamish River system in September, and migration continues through December. Spawning occurs from mid- to late October through December. Chum fry emerge in March through May, and they leave the freshwater system almost immediately to rear in the lower estuary (Miller and Somers 1989).

Steelhead that use tributaries in the lower Stillaguamish River system are winter-run steelhead. Adult winter steelhead begin their upstream migrations in early November through April with spawning occurring from March through mid-June (WSCC 1999). Juvenile steelhead typically rear in freshwater for over a year before they begin their seaward outmigration between April and June (WSCC 1999).

Sea-run coastal cutthroat begin entering the Stillaguamish River system in late July. Spawning occurs from mid-February through mid-May (WSCC 1999). Sea-run coastal cutthroat typically rear from two to four years in freshwater before migrating to the marine waters of Puget Sound, where they spend approximately two to five months before returning to the Stillaguamish watershed (Spence et al. 1995). Resident adult and juvenile cutthroat are expected in Secret Creek year-round.

4.2 Existing Habitat

Roadways, low-density residential development, and some small hobby farms are the primary factors affecting habitat and access to that habitat within the Secret Creek drainage. In general, the riparian corridor is more than 150 feet wide; however, the forested stands are young, and they are dominated by deciduous species. Reed canarygrass is also prevalent along much of Secret Creek, which has resulted in significant sediment retention and degradation of spawning habitat. Secret Creek is not identified on the 303(d) list of impaired waterbodies for any water quality parameter; however, Pilchuck Creek downstream of the confluence with Secret Creek has a total maximum daily load (TMDL) in place for dissolved oxygen, temperature, and bacteria (Washington State Department of Ecology [Ecology] 2020).

4.2.1 Immediate Crossing

The current crossing (Site ID 990622) is identified as a partial barrier to fish passage. This designation is due to the water surface drop at the culvert outlet (WDFW 2019; WDFW 2020).

The stream channel immediately downstream of subject culvert outlet is confined within a riprap-lined channel with an associated fishway. The fishway contains five channel spanning log grade control structures extending downstream to the private culvert beneath Dahl Road. Habitat can be characterized as step/pools extending from the culvert outlet downstream to Dahl Road. The pools are typically greater than 3 feet deep, and they likely provide good holding water for both juvenile and adult salmonids; however, limited riparian cover in this area reduces the quality of the pools to some degree. Substrates are dominated by medium- to large-size gravels; however, this material is heavily embedded with fines. Riparian vegetation is dominated by deciduous species including red alder, Oregon ash with some interspersion of immature western red cedar, Sitka spruce, and Pacific willow. Understory vegetation includes vine maple, sword fern, salmonberry, Himalayan blackberry, and reed canarygrass. Substrates consisted of a mixture of cobble and large gravel heavily embedded with fines.

The channel upstream of the culvert inlet is confined within a straight channel within the I-5 median with significant riprap armoring throughout. Habitats are characterized as a series of riffles and glides. Gravels are present, but they are heavily embedded with fines and cemented. Riparian vegetation is dominated by black cottonwood, red alder, and bitter cherry with an understory of sword fern, salmonberry, Indian plum, reed canarygrass, and Himalayan blackberry. Large woody debris is present, but these pieces are typically channel spanning and above the bankfull channel; therefore, they currently contribute little to channel and habitat complexity. The channel exhibited more sinuosity, and the riparian vegetation contained a higher conifer species component, including western red cedar and western hemlock; however, deciduous species-maintained dominance throughout the reach. Understory vegetation was more diverse than that downstream, and it included salmonberry, stink currant, red elderberry Indian plum, red-twig dogwood slough sedge, lady fern, horsetail, and creeping buttercup. Reed canarygrass was significantly denser upstream of the culvert. As such, the natural process of sediment sorting has been altered, and there is a significant increase in fine sediment bedload upstream of the culvert as opposed to downstream. While fine sediment dominated much of the reach, areas of suitable spawning gravel were observed. Areas of bank erosion and undercutting were observed, particularly closer to the culvert inlet. LWM was more abundant than downstream and typically within the active channel, but it was still primarily deciduous material.

Overall, there was some suitable spawning and rearing habitat within the assessed reaches at the culvert inlet and outlet. However, the quality of this habitat was reduced by fine sediment inputs, lack of instream woody material and cover, and lack of channel complexity resulting from channel confinement.

4.2.2. Quality Within Reach

WDFW (1997) conducted habitat surveys upstream of the subject crossing. The surveys were conducted to determine the quality of upstream habitat and to get an overall estimate of available spawning and rearing area that would be accessible to salmonids if the barrier were made 100 percent passable.

Riparian cover within the reach consists primarily of deciduous species, including red alder and black cottonwood with dense understory vegetation and some interspersion of coniferous species. The coniferous species include western red cedar and Sitka spruce. Overall canopy cover estimates are good and range between 80 and 90 percent. Instream cover was also abundant throughout the reach, which improves the quality of the reach for rearing habitat. Overall, substrates are dominated by gravel with sand being subdominant throughout the assessed reaches. While gravels are the dominant substrate, sand accounts for a large percentage of substrate composition within each reach, and this likely limits the ability of upstream reaches to provide high quality spawning habitat.

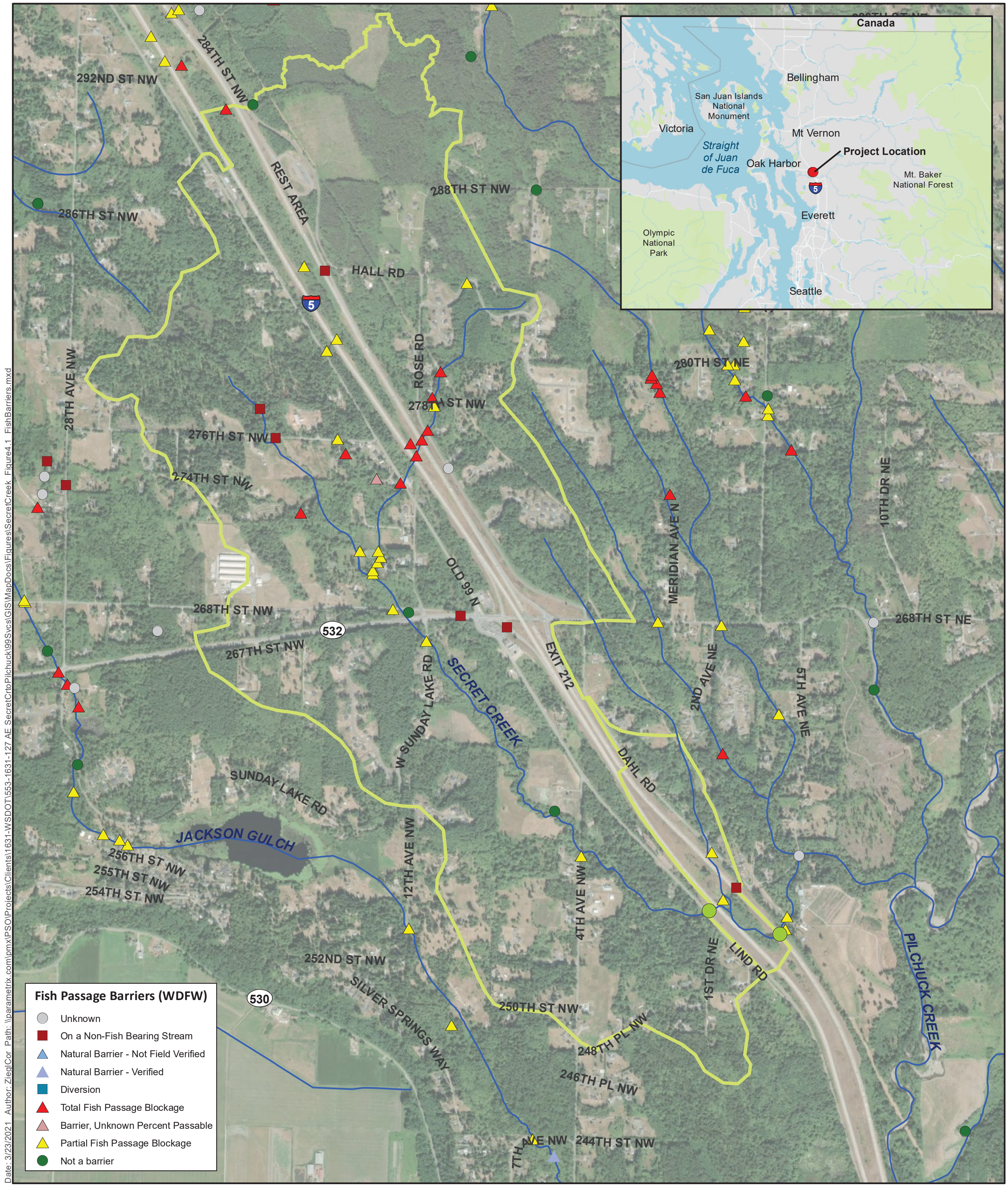
Pools and riffles dominate the habitat types throughout the reach. Pool habitats accounted for 49 percent of all habitat types, followed by riffles at 33 percent, and ponded areas at 18 percent. Pool habitat quality is improved by both abundant instream and good canopy cover. Pool quality would be much higher if the pools were deeper and if volumes were not reduced by fine sediment inputs. The reach provides some suitable spawning gravels; however, like pools, the quality has been reduced by fine sediment. The limiting factor with the highest degree of impact on suitability of the habitat for salmonid use is low summer flows followed by lack of suitable spawning gravels.

4.2.3 Length of Potential Gain

WDFW (2019) performed a habitat survey upstream from the culvert and reported 5.1 miles of potential fish habitat upstream of the subject culvert. Of that habitat gain, 50,311 square feet/1.15 acres is spawning habitat and 185,828 square feet/4.27 acres is rearing habitat. Habitat gain includes the mainstem and three tributaries.

4.2.4 Other Barriers in System

WDFW (2019) reported two downstream barriers that were corrected in 2000. The barriers are identified as currently passable, but the percent passage is listed as unknown (Figure 4.1, Secret Creek Fish Barriers). Upstream barriers include five partial barriers on the mainstem Secret Creek; a tributary to Secret Creek containing two partial barriers, two corrected barriers that are currently not passable, and a barrier with unknown passage status; there is one other tributary with an impassable barrier. Numerous barriers are reported in the Pilchuck Creek watershed, but there are no impassable barriers downstream of the confluence with the mainstem Pilchuck Creek. The partial barrier immediately upstream (Site ID 990623) and beneath the SB lanes of I-5 is also currently being evaluated for replacement with a fish-passable culvert.



Source: Snohomish County, ESRI, WSDOT, WDFW

Secret Creek Culverts at I-5

Watercourse

Secret Creek Watershed Boundary

0 750 1,500 3,000 Feet

Figure 4.1 Fish Barriers

I-5 Secret Creek

Snohomish County, WA

4.2.5 Other Restoration Efforts in System

The larger Stillaguamish watershed has been identified as a high priority for salmon recovery in the Puget Sound region, particularly for restoration of several habitat factors that limit salmon productivity, including the restoration of riparian habitat, floodplain habitats, and large wood (SIRC 2005). The Lower Pilchuck Creek sub-basin and tributaries, including Secret Creek, have been identified as a riparian priority sub-basin due to high use by Chinook salmon or proximity to areas of high use (SCD 2017). The riparian corridor within the lower Pilchuck Creek sub-basin has been identified as 67 percent functional with a goal of 80 percent. The creation of pool scour in flow-gaining reaches and riparian plantings to provide temperature and salmon habitat benefits are current priorities (SWC 2015). Conservation actions important for salmon recovery in the sub-basin include invasive vegetation control, riparian reforestation, exclusion fencing, and protection of existing riparian forest habitats.

The National Estuary Protection (NEP) funded by the Environmental Protection Agency (EPA) and administered by Ecology in cooperation with the National Oceanographic and Atmospheric Administration's National Marine Fisheries Division, Snohomish County, and the Snohomish Conservation District (SCD), are currently seeking opportunities to work with property owners to purchase permanent easements along Secret Creek and lower Pilchuck Creek to meet the riparian restoration goals set forth for the subbasin.

5.0 Reference Reach Selection

The analysis and design is based off of two reference reaches, one upstream and adjacent to the SB I-5 crossing and the other downstream of NB I-5 and Dahl Road. Observed similarities in the channel and valley geometry characteristics upstream of the SB I-5 crossing and the reference reach downstream of the Dahl Road crossing, the relatively less managed condition of these reaches, and modeling which indicates the channel floodplain is not disconnected all provided validation for the selected reference reaches. See Figure 2.1, Project Area, for the location of the reference reaches and Section 2 and Section 3 for more detail.

As reported in Section 3.4.1 – Channel Geometry, average stream gradients vary slightly based on source (either the site survey from 2019, or the LiDAR imagery from 2017) and the extents of the profile analyzed. Within the limits of the WSDOT site survey, an average gradient of 1.30 percent exists through the reference reach downstream of Dahl Road, and an average gradient of 0.59 percent exists upstream of SB I-5. This length of survey is not sufficient to average out the effect of the large pool directly upstream of the culvert inlet on the gradient, therefore, the surveyed gradient of 0.59 percent does not well represent the reference reach gradient. According to LiDAR analyzed, the reach downstream of Dahl Road averages 1.53 percent and the reach upstream of SB I-5 averages 1.11 percent. The proposed gradient of 1.37 percent matches closest to the reach downstream of Dahl Road per site survey and is an average of the upper and lower reference reaches per LiDAR analysis.

The three pebble counts performed downstream of the NB I-5 crossing in the downstream reference reach will be used as reference for the design since stream gradient and confinement in the downstream reference reach more closely match proposed channel conditions.

6.0 Hydrology and Peak Flow Estimates

The basin receives a mean annual precipitation of 36.8 inches as obtained from the National Hydrography Dataset and reported by USGS StreamStats. The PRISM Climate Group reports a mean annual precipitation of 46.2 inches obtained from data between 1981 and 2010.

The WDFW Water Crossings Manual (2013) recommends four methods for determining hydrology in the design of culverts for fish passage. The four methods are, in order of preference, stream gauging, continuous-simulation modeling, local-regression models, and regional-regression models. Neither stream gauging nor local-regression models are available for Secret Creek.

A continuous-simulation hydrologic model based upon the Hydrological Simulation Program (HSPF) was developed for the Secret Creek watershed. The modeling software MGSFlood was used to produce this model. It incorporates existing land use conditions and underlying soil types to produce calculated peak flow rates. The latest USGS regional regression equation for Region 3 in Washington was also applied to the watershed with results reported below (Mastin et al. 2016). The regression equations provided by Mastin et al. apply to watersheds with impervious areas of 5 percent or less. Secret Creek has an impervious percentage of 9.5 percent; therefore, the USGS regression equations are likely to underestimate peak flow values. Due to the high percentage of impervious area and because they provide a more conservative estimate, the peak flow values from the MGSFlood continuous-simulation model will be used for the hydraulic analysis of Secret Creek. The continuous-simulation hydrology selection is supported by comparing existing conditions model results with an observed moss line at the outlet of the upstream SB I-5 culvert. Based on scaling of a photograph, the moss line appears about 3.3 feet below the soffit, or 3.7 feet above the invert of the culvert at the outlet. Hydraulic modeling of the existing conditions indicates that the 2-year water depth at the outlet is 3.5 feet. The similarity in data supports the selection for the hydrology at this crossing. The hydrology between the SB and NB crossings differs by between 7 percent and 9 percent due to a small tributary input between the crossings. See the SB I-5 Secret Creek PHD for more information.

As discussed in Section 3.1, 2.61 square miles flows to the NB I-5 Culvert. Of this 2.61 square miles, 2.49 square miles flow to the NB I-5 culvert via Secret Creek beneath the SB I-5 culvert. The remaining 0.12 square mile comes from an unnamed tributary that collects runoff from I-5 and along the highway's east side. This unnamed tributary crosses NB I-5 via a 3-foot-diameter, corrugated-steel culvert pipe and enters Secret Creek a few hundred feet downstream of the SB I-5 culvert in the median area between the NB and SB I-5 culverts. The flows from the unnamed tributary contribute approximately 9 percent of the total peak flow rate for the two-year event and 7 percent for the 100-year peak flow event. MGSFlood results for the watershed contributing to the NB I-5 crossing are presented in Table 6.1 below. See Section 7.1 for further model discussion.

Table 6.1. Peak flows for Secret Creek at NB I-5 Crossing

Mean Recurrence Interval (MRI)	HSPF-based Continuous-Simulation Model (cubic feet per second [cfs])	USGS Regression Equation (Region 3) (cfs)
2	**73**	56
10	**139**	112
25	**172**	141
50	**218**	163
100	**278**	187
200	**296**	211
500	**318**	244

7.0 Hydraulic Analysis

The hydraulic analysis of the existing flow conditions and the preliminary design of the NB I-5 Secret Creek crossing was performed using the U.S. Bureau of Reclamation's SRH-2D computer program—a two-dimensional numerical hydraulic model. Two scenarios were analyzed for determining stream characteristics for Secret Creek with the SRH-2D models: 1) existing conditions with a 240-foot-long, 8-foot-diameter steel culvert; and 2) future conditions with a crossing with a minimum hydraulic opening of 40 feet.

7.1 Existing Conditions—240-foot-long, 8-foot-diameter Steel Culvert

The existing channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the project engineer's office. The data were developed from topographic surveys Parametrix surveyors performed in November 2019. LiDAR data obtained in 2017 were used as necessary where survey data were not available. The model extends 1,000 feet downstream of the Dahl Road culvert outlet and 1,200 feet upstream of the SB I-5 culvert inlet.

The SMS SRH-2D model incorporates a channel roughness in the two-dimensional mesh representation of space. Roughness values were determined based on field observations of the channel and overbank surface material, surface irregularity, variation in channel section size and shape, physical obstruction including boulders and woody material, and live vegetation. A roughness coefficient for the channel and overbanks was then computed based on the criteria Chow (1959) developed.
Table 7.1 documents the roughness coefficients in terms of Manning's n value.

Table 7.1. Manning's Roughness Coefficients Used in Existing Conditions Model

Value Used	Left Overbank Area	Main Channel	Right Overbank Area	Existing Baffled Culvert
Manning's 'n' Value	0.065	0.046	0.065	0.035

The project channel and surrounding area surfaces were imported into SRH-2D. Using the surveyed surface and supplemental LiDAR data as needed, a mesh was created to represent the existing condition. A mesh is a group of building blocks that is used to calculate depth, velocity, and other hydraulic parameters at each block.

The mesh density consists of approximately 34,500 elements. The elements along the stream and floodplain have approximately 2- to 5-foot vertex spacing. The existing culverts at SB I-5, NB I-5, and Dahl Road were represented in the HY-8 culvert analysis software (FHWA 2016) to calculate the hydraulics through the crossing. Appendix C contains the SRH-2D model results of the existing stream and crossing.

Two upstream boundary conditions were implemented in this model to define inflow (see Section 6.0 for peak flow rates). The first boundary condition was approximately 1,300 feet upstream of the SB I-5 culvert inlet along the main channel of Secret Creek. This boundary condition location was placed far enough from the project site so that it would not influence hydraulic results at the crossing. The second upstream boundary condition was placed at the north end of Secret Creek in the median between NB and SB I-5. This is where an unnamed tributary crosses beneath NB I-5 (Site ID 99609) and drains into Secret Creek. The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes. The model was run in steady-state mode for all modeled simulations.

The downstream boundary condition location was placed approximately 1,000 feet downstream of the Dahl Road Culvert outlet, far enough from the project site so that it would not influence the hydraulic results at the crossing. The downstream boundary condition estimated the water surface elevations using normal depth at the average gradient and corresponding peak flow being modeled.

Table 7.2 shows the water surface elevations at the existing NB I-5 culvert inlet, flow velocities at the existing NB I-5 culvert outlet, and the average channel velocity approximately 720 feet upstream of the existing NB I-5 culvert inlet. Average upstream channel velocities were taken 720 feet upstream of the culvert inlet so that the velocity values would not be affected by the backwater occurring at the NB I-5 culvert inlet. Figure 7.1 depicts the water surface elevation profile of the existing NB I-5 crossing.

Table 7.2. Water Surface Elevations and Velocities for Existing Conditions at NB I-5 Crossing

Elevations and Velocities	2-Year Flow	25-Year Flow	100-Year Flow
Water Surface Elevation at the Existing Inlet (feet [ft])	117.8	119.6	121.2
Existing Structure Outlet Velocity (ft per second [ft/s])	5.02	9.18	14.99
Average Upstream Channel Velocity (ft/s)	2.70	2.75	2.80

Table 7.3 shows the water surface elevations at the existing Dahl Road culvert inlet, flow velocities at the existing Dahl Road culvert outlet, and the average channel velocity approximately 65 feet upstream of the existing Dahl Road inlet.

Table 7.3. Water Surface Elevations and Velocities for Existing Conditions at Dahl Road Culvert

Elevations and Velocities	2-Year Flow	25-Year Flow	100-Year Flow
Water Surface Elevation at the Existing Inlet (feet [ft])	101.4	102.1	103.2
Existing Structure Outlet Velocity (ft per second [ft/s])	2.6	4.3	5.5
Average Upstream Channel Velocity (ft/s)	2.3	2.9	3.3

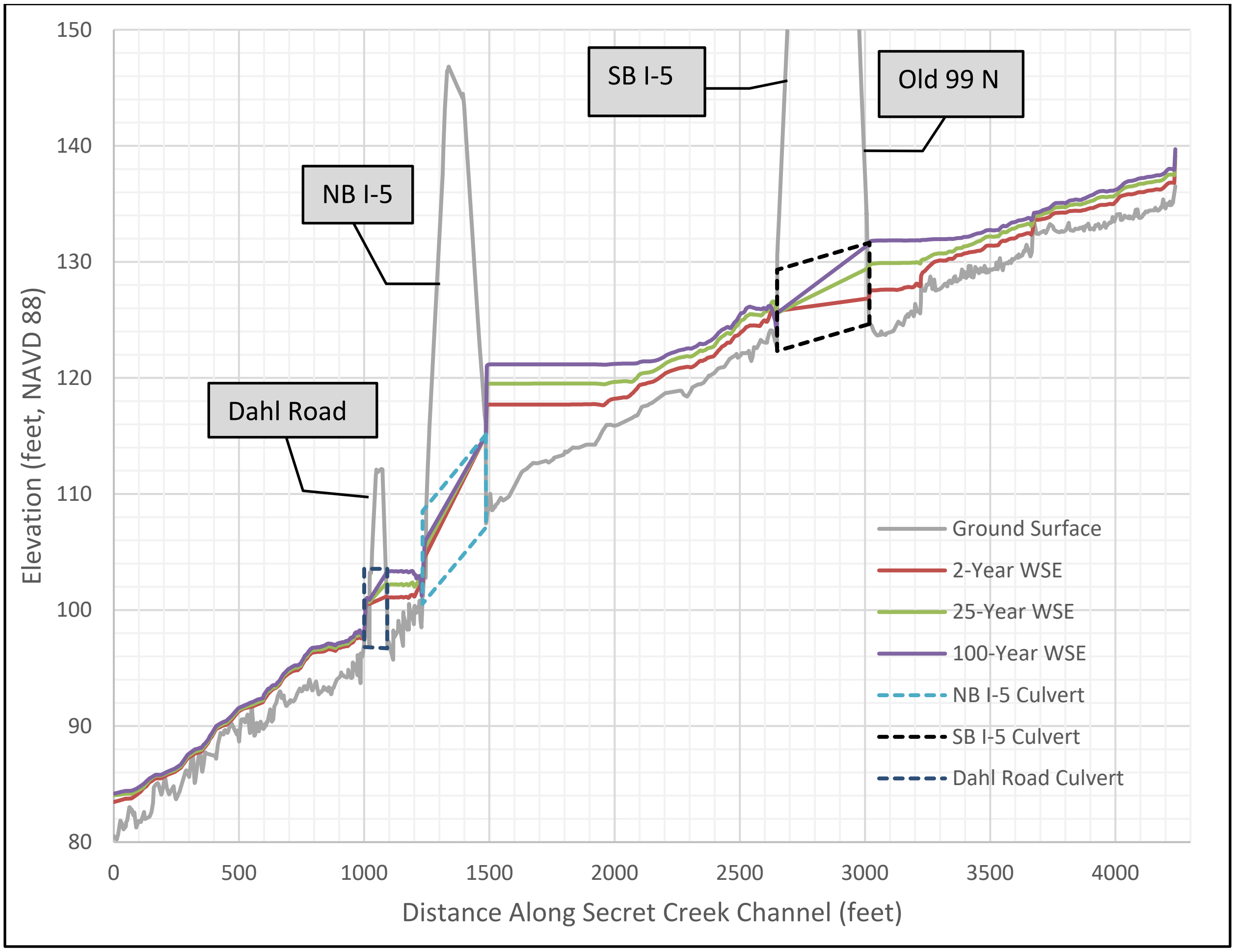


Figure 7.1. Water Surface Elevations at Existing NB and SB I-5 Crossings

7.2 Future Conditions – Proposed 40-foot Span Structure

The preliminary design proposes a minimum hydraulic opening of 40 feet at the crossings of Old 99 North and SB I-5. The proposed stream corridor through the crossings was designed to accommodate channel meander by mimicking relatively unmanaged conditions identified upstream and downstream of the crossing, and this formed the basis of a natural conditions model. The corridor width of the natural conditions model is 64 feet wide to accommodate these meanders. To evaluate the bridge design criteria, the model was then modified by encroaching into the floodplain by selectively removing portions of the mesh and replacing them with vertical walls beneath the footprints of both the Old 99 North and SB I-5 conditions model is 64 feet wide to accommodate these meanders. To evaluate the bridge design criteria, the model was then modified by encroaching into the floodplain by selectively removing portions of the mesh and replacing them with vertical walls beneath the footprints of both the Old 99 North and SB I-5 pavements. Based on the velocity results from this encroachment testing, a minimum hydraulic opening of 40 feet is proposed. Section 8.2.1 describes the analysis in determining the minimum hydraulic opening in more detail, and Sections 8.2.3 and 9.1 describe the design in more detail.

The roughness coefficients for the channel and overbanks were computed based on criteria Chow (1959) developed for the future condition. Table 7.4 documents the roughness coefficients in terms of Manning's n value.

Table 7.4. Manning's Roughness Coefficients Used in Proposed Conditions Model

Value Used	Left Overbank Area	Main Channel	Right Overbank Area
Manning's 'n' Value	0.070	0.056	0.070

The proposed channel and surrounding area, including the NB I-5, SB I-5, and Dahl Road crossings, were imported from Microstation InRoads into SRH-2D. Using the surveyed surface and supplemental LiDAR data as needed, a mesh was created to represent the proposed condition. The mesh density of this scenario consists of approximately 36,400 elements. The elements along the stream and floodplain have approximately 2-foot to 5-foot vertex spacing. Hydraulic results for the proposed NB I-5 crossing and the existing Dahl Road culvert, to remain, are summarized in Table 7.5 and Table 7.6 respectively. Average channel velocity and average channel shear stress are reported at the middle of the proposed crossings.

Table 7.5. Water Surface Elevations, Velocities, and Shear Stress at Proposed Northbound Interstate 5 Crossing

Elevations, Velocities, and Shear Stress	2-year Flow	100-year Flow	500-year Flow	100-year (2080) Flow
Water Surface Elevation at Upstream of Crossing (ft)	103.6	104.9	105.2	105.4
Average Channel Velocity Within Crossing (ft/s)	3.5	5.0	4.9	4.6
Average Channel Shear Stress within Crossing (lb/ft^2)	1.0	1.7	1.7	1.3

Table 7.6. Water Surface Elevations and Velocities for Proposed Conditions at Existing Dahl Road Culvert

Elevations and Velocities	2-Year Flow	100-Year Flow	500-Year Flow	100-year (2080) Flow
Water Surface Elevation at the Existing Inlet (feet [ft])	101.5	103.2	104.0	104.5
Existing Structure Outlet Velocity (ft per second [ft/s])	4.4	6.4	7.1	7.7
Average Upstream Channel Velocity (ft/s)	2.0	3.3	3.`1	2.9

The model's upstream and downstream boundary conditions remained the same as the existing conditions model. The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes and the model was run in steady-state mode for all modeled simulations. Appendix D contains the SRH-2D model results of the proposed conditions. Figure 7.2 depicts the water surface elevation profile of the proposed crossing. Figure 7.3 depicts the water surface elevations relative to a typical section within the proposed NB I-5 crossing. The cross section was taken perpendicular to the main channel at a skew within the crossing, which makes the opening appear wider than it is.

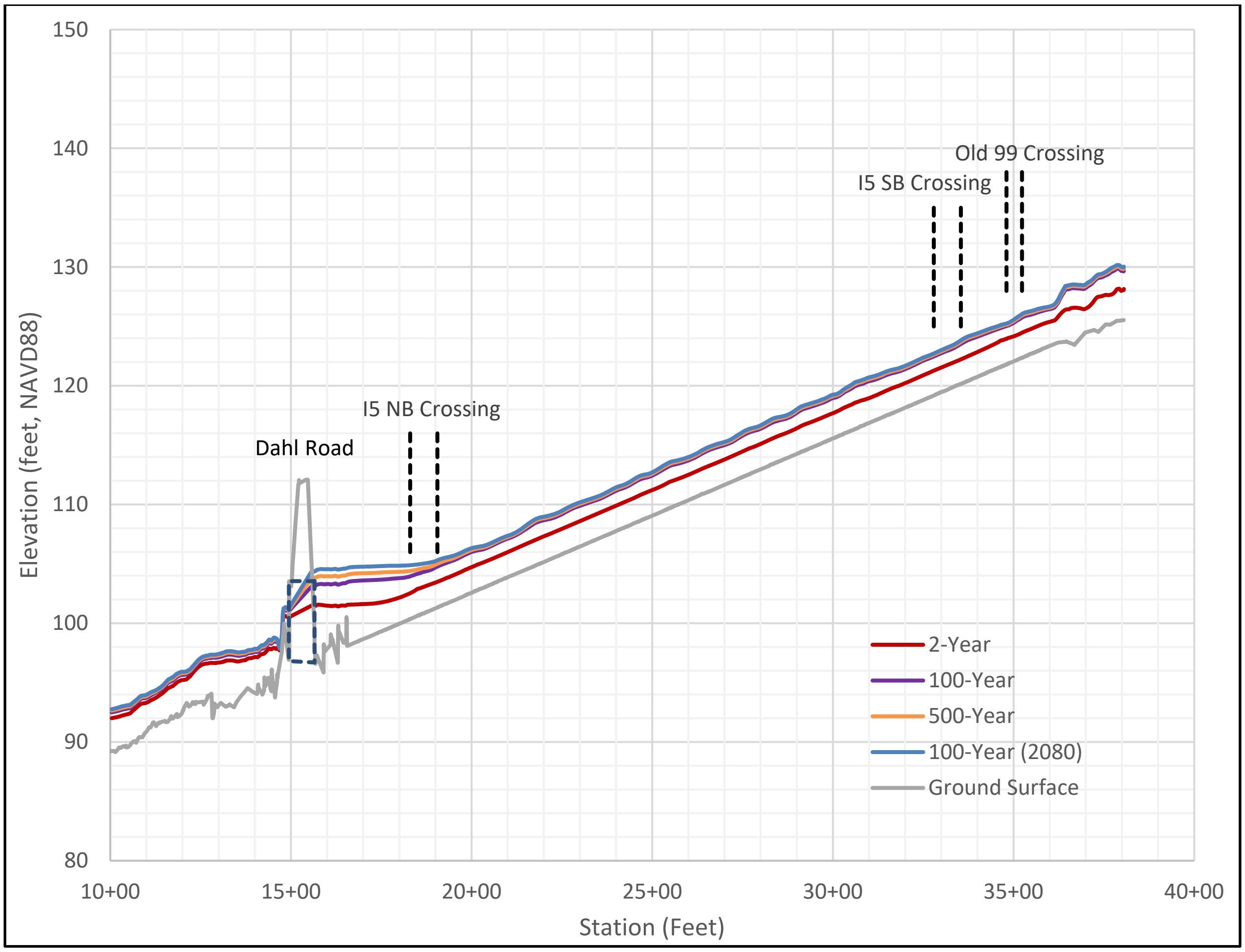


Figure 7.2. Water Surface Profile at Proposed NB I-5, SB I-5, and Old Highway 99 Crossings

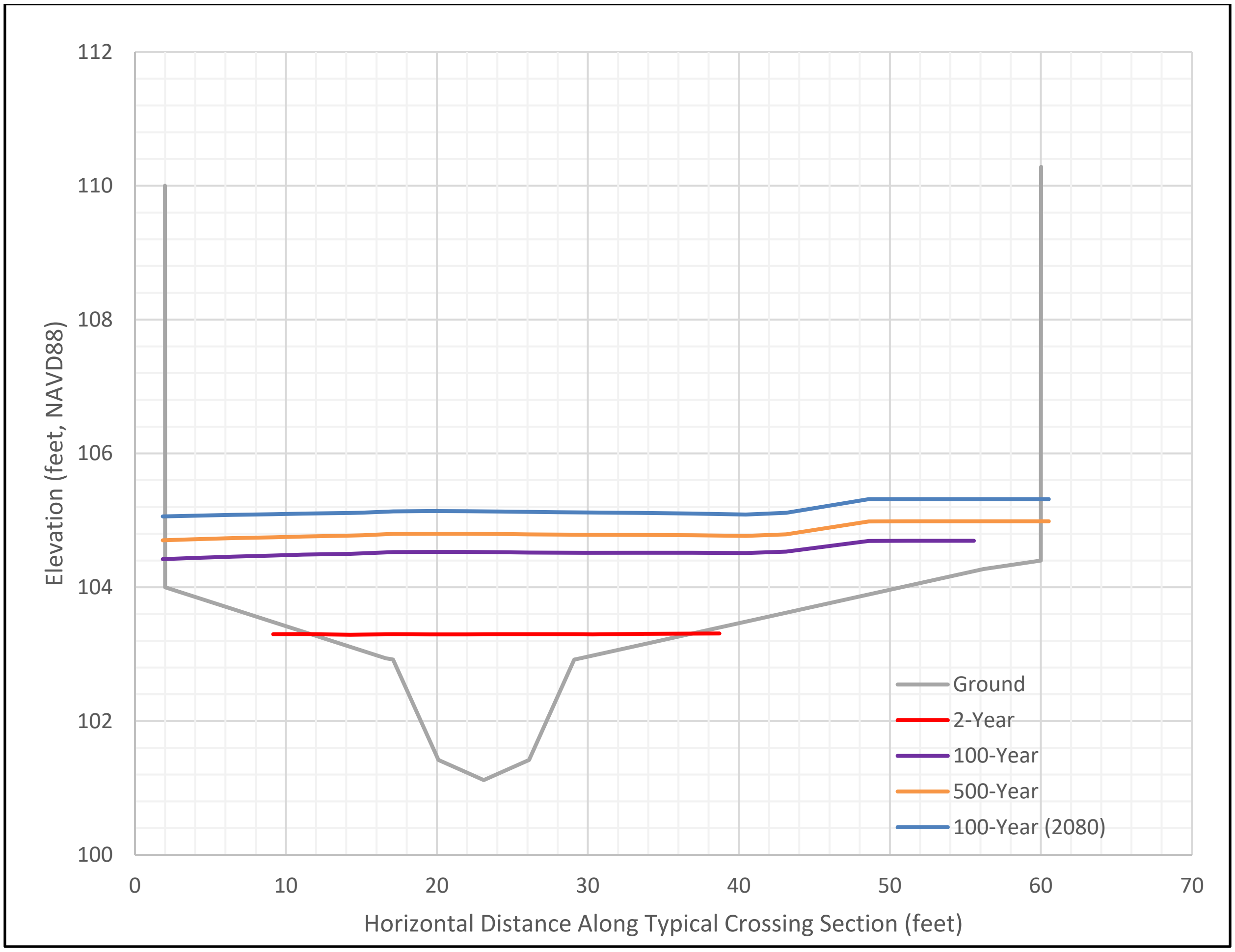


Figure 7.3. Proposed Typical Section with 64-foot Corridor Width

8.0 Fish Passage Design Methods Selection

8.1 Design Methodology Selection

The WCDGs contain methodology for five different types of crossings: no-slope culverts, stream simulation culverts, bridges, temporary culverts or bridges, and hydraulic design fishways. The permanent federal injunction allows for the use of the stream simulation method and bridge design method, unless extraordinary circumstances exist on the site. According to the WCDG, a bridge should be considered for a site if the following factors apply: the FUR is greater than 3.0, the stream has a BFW greater than 15 feet, the channel is believed to be unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, or the culvert would be very long. The bridge design method was selected primarily because the FUR is greater than 3.0 and a proposed replacement culvert could be up to 255 feet long.

8.2 Bridge Design Criteria

The 2013 WDFW WCDGs present two methodologies for designing a bridge crossing: confined bridge design and unconfined bridge design. The method to be used is defined by the FUR. The FUR is defined as the FPW divided by the BFW. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. A ratio under 3.0 is considered a confined channel, and a ratio above 3.0 is considered an unconfined channel.

The FUR was determined by comparing the 100-year water surface from the existing conditions model to the agreed-upon BFWs measured outside of the influence of the existing crossing. FPW values were taken downstream of the Dahl Road culvert, within the reference reach. The 100-year water surface varied between 50 and 62 feet wide and averaged approximately 56.7 feet wide. Dividing the average FPW by the BFW of 12.0 feet results in an average FUR of 4.7. The FUR is above the threshold of 3.0, supporting an unconfined bridge design approach as described in the WCDG.

8.2.1 Unconfined Bridge Design Width Criteria

For unconfined systems, the minimum hydraulic opening is defined by a ratio of the average main channel velocity within the proposed crossing to the average main channel velocity immediately upstream in a natural conditions model where the roadway fill is completely removed from the model. Unconfined bridge designs limit the encroachment of crossing structure on floodplain by targeting a maximum velocity ratio of 1.1.

A natural conditions model was developed in which the roadway embankment was removed from the corridor, producing a proposed corridor which is based off the morphology and hydraulics of the reference reach. See Sections 8.2.3 and 9.0 for additional discussion on channel geometry. To determine the minimum hydraulic clear span, a sensitivity analysis was conducted on the effect that encroachment has on the velocity ratio. Since the hydraulic model and analysis includes the Old 99 North, SB I-5, and NB I-5 crossings in one model the velocity ratio analysis was performed jointly. Encroachment on the floodplain was applied beneath each of the three roadway pavements. The encroachment was skewed so that the inside faces of the crossings were oriented parallel to the overall channel alignment through the crossing, with skew angle not exceeding 30 degrees to perpendicular of the roadway for constructability.

It was observed that the average main channel velocity in the natural conditions model at the location of the proposed SB I-5 crossing was higher than the average main channel velocity in the natural conditions model immediately upstream of the proposed SB I-5 crossing, creating a natural velocity ratio that exceeds 1.1 at the location of the proposed crossing. This relationship skews the evaluation of velocity ratios as defined above and does not well represent the intent of the evaluation, since no amount of encroachment can be removed from the model to bring the velocity ratio to 1.1 or below. Therefore, the velocity ratios presented here compare the average main channel velocity within the proposed crossing encroachment to the average main channel velocity at the location of the proposed crossing in the natural conditions model. For consistency, this approach was also applied to the subject of this report, the NB I-5 crossing.

Table 8.1 below presents current 100-year and projected year 2080 100-year flow velocities and velocity ratios.

Table 8.1. Velocity Comparison for 40-foot Structure at NB I-5

Locations	100-year Velocity (cfs)	Projected 2080 100-year Velocity (cfs)	Difference (cfs)
Upstream of Structure (Natural Conditions)	**4.7**	**4.7**	**0**
Through Structure	**4.5**	**4.4**	**-0.1**
Velocity Ratio	**1.0**	**0.9**	**-**

The NB I-5 crossing presents a velocity ratio of 1.0 for the current 100-year flow event, and 0.9 for the 2080 100-year event. Therefore, the proposed 40-foot minimum opening satisfies unconfined bridge design criteria.

Structure width must also consider the free passage of LWM. Per the WSDOT HM Section 10-8.1, if the length of wood with root wads is less than 75 percent the span of the downstream crossing, or if the length of wood without root wads is less than 100 percent the span of the downstream crossing, then it is assumed that the risk of the wood lodging on the crossing is low. With a proposed minimum span of 40 feet, it could be expected to pass wood with root wads up to 30 feet in length or wood with no root wads up to 40 feet. Most of the wood observed upstream of the SB crossing was 25 feet or less in length. Placement of LWM under the crossing structure will require approval by HQ Hydraulics, but it is assumed that logs 30 feet long, that meet the requirements of a key piece, could be placed across the floodplain within the crossing.

8.2.2 Backwater and Freeboard

The WCDGs recommend the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate and that allow the free passage of debris expected to be encountered. Washington Administrative Code 220-660-190 requires a minimum 3-foot freeboard over the 100-year water surface elevation for bridge designs. It is practicable to meet the minimum 3 feet of freeboard over the 100-year water surface elevation at this crossing. The existing NB I-5 roadway elevation is approximately 143 feet at the upstream (west) side of the roadway. Assuming a conservative crossing structure thickness of 10 feet, this would give a low-chord elevation of 133 feet. The 100-year water surface elevation at the upstream end of the proposed crossing is approximately 104.9 feet. This provides 28.1 feet of freeboard for the 100-year flow. Additionally, a minimum of 10 feet above the channel thalweg should be provided, if practicable, for constructability, future maintenance, and performing monitoring activity.

8.2.3 Channel Planform and Shape

The WCDGs require that the channel planform and shape mimic conditions within a reference reach, and the reference reaches identified adjacent to and upstream of the SB I-5 crossing and downstream of Dahl Road provides a target for the design of these characteristics. Measurements were made in MicroStation using site survey and LiDAR imagery within the reference reaches to determine a meander radius of curvature range, meander wavelength range, and meander belt width. The radius of curvature was measured within a range from 20 feet to 60 feet, averaging approximately 35 feet. Average meander wavelength was measured as approximately 165 feet, and meander belt width was consistent with valley bottom width and ranged from 54 feet to 88 feet. Historical Right-of-Way plans were also reviewed and support these planform dimensions.

Additionally, channel geometry design guidance was used to validate the typical channel geometry determined from the reference reach. The U.S. Army Corps of Engineers' Channel Restoration Design for Meandering Rivers (Soar and Thorne 2001) presents expressions based on a composite of relationships between meander wavelength, radius of curvature, and meander amplitude relative to channel BFW from a large sample of meandering channels. Using the results from these expressions for validation purposes, Secret Creek could be represented with an average radius of curvature of approximately 30 feet, a meander amplitude of approximately 60 feet, and meander wavelength of between 135 feet and 150 feet. Based on these stream measurements, design guidance, and the intent to connect to the existing channel alignment as naturally as possible, a design radius of curvature range of 10 feet to 45 feet at main channel centerline, a design meander belt width of 64 feet, and meander wavelengths between 100 and 170 feet were implemented in the proposed design.

8.2.4 Floodplain Continuity and Lateral Migration through Structure

Outside of the crossings, the channel meander belt width has been designed to mimic the meander belt width in the reference reaches, which provides space for the stream to meander within the valley confines similarly to the reference reach. The resulting 100-year peak flow event engages the floodplain and corridor similarly to the reference reach as well. Please see Appendix D for model results depicting the water surfaces through the proposed design, as well as in the reference reaches at the upper and lower extents of the model to compare design to reference reach.

The WCDGs require that the design maintains floodplain continuity. Velocity ratios, presented in the WCDG and HM as the primary metric to determine minimum opening for unconfined systems, indirectly assesses floodplain connectivity by maintaining that any encroachment on the floodplain is limited to the fringes where flows are negligible and not expected to play a significant role in the hydraulic functioning of the channel. The design analysis in Section 8.2.1 above includes minimizing increases in velocity through the crossing in the 100-year and 2080 100-year peak flow events so that the crossings have minimal impact to the hydraulic functioning of the channel within the crossings.

The WCDGs also require that bridges account for lateral channel movement that will occur in their design. The proposed crossing width allows for 28 feet of lateral channel movement. The tops of any structural footings shall be located to a depth such that they will remain below the 500-year total scour. The scour analysis, to be performed during the final design phase, will include calculations that assume the main channel has migrated to the face of the bridge abutment for design purposes to ensure any bridge abutments do not preclude channel vertical channel adjustment or cause structural stability concerns.

8.2.5 Channel Gradient

The WCDGs recommend, to the extent compatible with safety of the structure, its approach roads, and adjacent private property, allowing natural evolution of the channel planform and longitudinal profile. The proposed channel slope is 1.37 percent. According to the 2017 LiDAR, the stream has an average gradient of 1.11 percent from the SB I-5 culvert inlet to 2,760 feet upstream. Compared to the surveyed upstream profile, the LiDAR average gradient is closer to natural gradients observed downstream and considers a much longer stretch of stream. For these reasons, 1.11 percent is taken as the reference reach gradient upstream of SB I-5. The proposed slope ratio is 1.19 (1.37 percent divided by 1.11 percent), less than the maximum of 1.25. The proposed slope connects the upstream profile to the downstream profile, while minimizing the length of channel regrade.

9.0 Streambed Design

The preliminary design presented in this report proposes to remove the existing concrete box culvert at the SB I-5 and Old 99 North crossing, remove the existing steel culvert pipe at the NB I-5 crossing, and to develop a new channel and crossing configuration. The new configuration extends from the upstream of the SB I-5 and Old 99 North culvert downstream to the outlet of the NB I-5 culvert. Changes to the channel and crossings and include a new horizontal main channel and corridor alignment, design profile, proposed channel cross-section, and streambed material. The design includes significant restoration work between the NB I-5 and SB I-5 pavements. Please see Appendix E for preliminary hydraulic plans.

9.1 Alignment

The proposed design includes extensive modification of the existing stream alignment and profile. Under the existing conditions, the stream crosses beneath Old 99 North and SB I-5 via a 366-foot-long, 7-foot-tall by 5-foot-wide concrete box culvert. The stream then enters the approximately 1,200-foot-long reach between NB and SB I-5 culverts. Finally, the stream crosses beneath NB I-5 via an 8-foot-diameter, 240-foot-long corrugated steel culvert. Under the proposed condition, the stream corridor generally follows the existing stream and culvert alignment to minimize the amount of cut and fill required, but the proposed corridor width has been increased to match the reference reaches and meander bends have been added throughout the entire proposed main channel horizontal alignment. The addition of meander bends through the proposed crossing more closely mimics the natural stream morphology encountered in the reference reach. The proposed channel planform utilizes an irregular pattern of meanders varying in radius of curvature of between 10 and 45 feet. Templates for the proposed meander patterns were taken from existing channel meander patterns in the surveyed reference reaches upstream of the SB and downstream of the NB crossings. The inclusion of meanders, in conjunction with LWM and other channel habitat features, including preformed pools and riffles, will be designed to provide improvements for fish habitat.

Grading is proposed to begin 17 feet downstream of the existing NB crossing culvert outlet at Station 16+92 and end 25 feet upstream of the existing SB I-5 culvert inlet at Station 36+17, for a total regrade length of 1,925 feet along the proposed horizontal alignment. This length of regrade will allow the proposed grade to tie into the existing upstream and downstream grades as naturally as possible, while minimizing the amount of excavation and impact to existing channel.

The proposed profile has been designed with a continuous 1.37 percent overall gradient. The upstream end of the profile has been designed to match the existing culvert inlet elevation so that the proposed channel elevation is not reduced in any way in comparison to the existing channel elevation. The downstream limit of channel grading occurs at the bottom of a pool immediately downstream of the existing NB I-5 culvert concrete apron and control weir. At the downstream end, the proposed profile does not include regrade through the 5 existing log grade control structures between Dahl Road and NB I-5, but these logs are to be removed as part of this project. The removal of these logs will inevitably result in morphological changes in the reach between Dahl Road and NB I-5 as the system equilibrates. Sediment contained upstream of the removed logs will likely settle into the scour pools immediately downstream of the log controls following removal, and some material may be mobilized further downstream by flow. Figure 9.1 below shows how the proposed profile ties into the existing channel, and how it aligns with the channel profile through the existing Dahl Road crossing and the existing channel downstream of the log grade controls serving the outlet of the Dahl Road crossing.

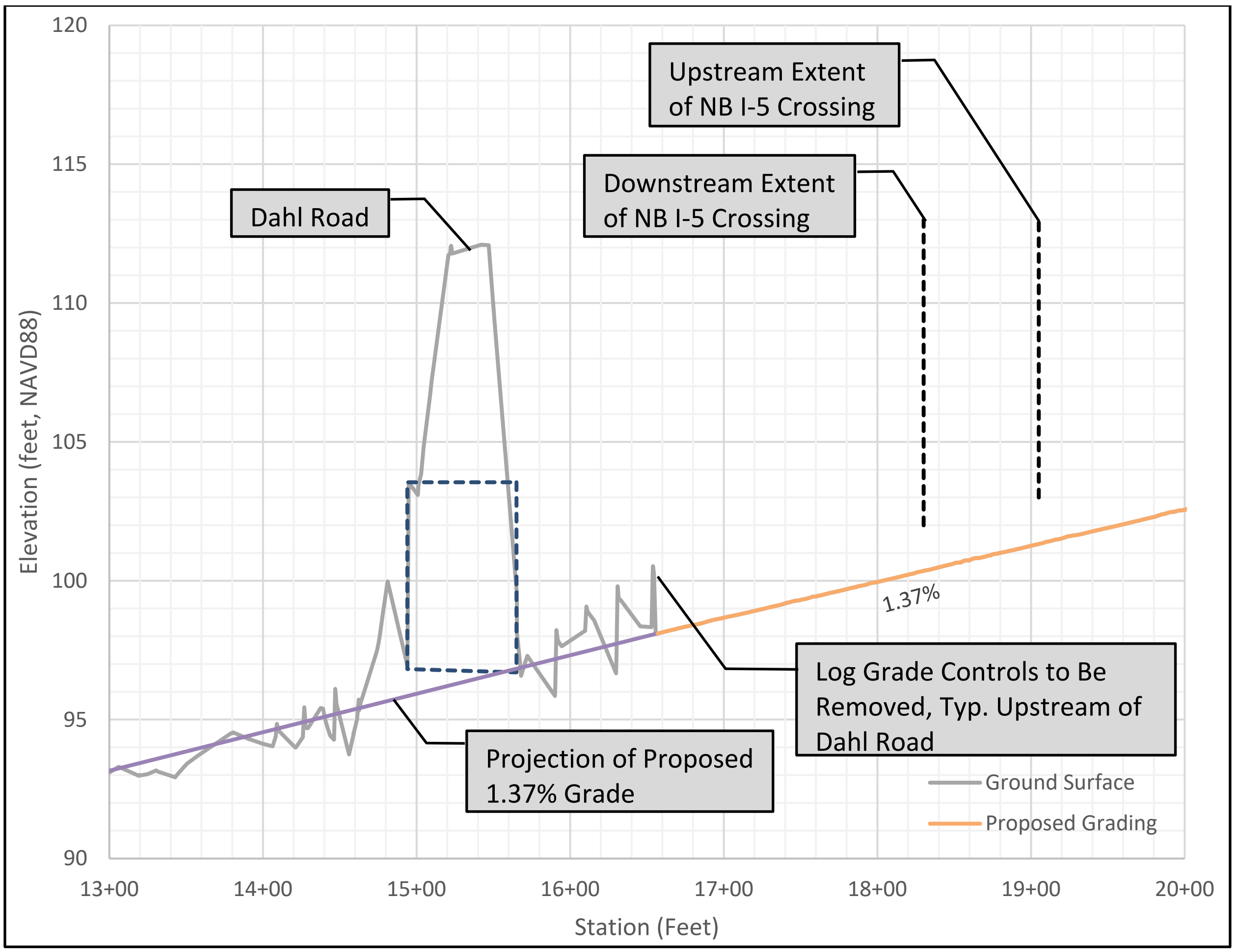


Figure 9.1. Dahl Road Log Removal Stream Profile

Previous iterations of the preliminary design did not propose a regrade of the reach between NB and SB I-5. Based on discussions following the WSDOT internal review process, it was decided that the preferred approach going forward would be to regrade the entire reach between the two crossings. This approach will reduce concerns about long term streambed regrade, is expected to provide aquatic habitat improvement, and generally improves continuity and stream function.

9.2 Proposed Section

The channel cross section has been designed to mimic the reference reach. The channel section was designed with bank slopes like existing Secret Creek cross-sections from the reference reach to maintain consistency in hydraulic performance between the reference reach and proposed channel.

In the proposed cross section through the crossing, a low-flow channel was created with channel bottom slopes of 10(H):1(V) extending 3 feet outward on each side from the channel center. The main channel was then designed with 2(H):1(V) slopes extending 3 feet outwards. This creates a main channel width of 12 feet, a main channel depth of 1.8 feet, and a resultant BFW to a maximum depth ratio of 6.7. The two-year water surface elevation was designed to exceed the breakover point of the floodplain, which is consistent with existing conditions modeling in the reaches upstream and downstream of the I-5 crossings. The low-flow channel will be refined in later stages of the project to connect habitat features together and to ensure that the project is not a low-flow barrier. The low-flow channel will be constructed as directed by the engineer in the field. Floodplain benches were designed with 20(H):1(V) slopes extending outward from the breakover point between the main channel and the floodplain to the edge of the floodplain for a total floodplain with of 64 feet. Finally, side slopes will extend out from the edge of the floodplain at 2(H):1(V) to tie into the existing surface. Figure 9.2 depicts a proposed cross section near the existing culvert outlet, with an existing cross section from just downstream of the culvert outlet for comparison.

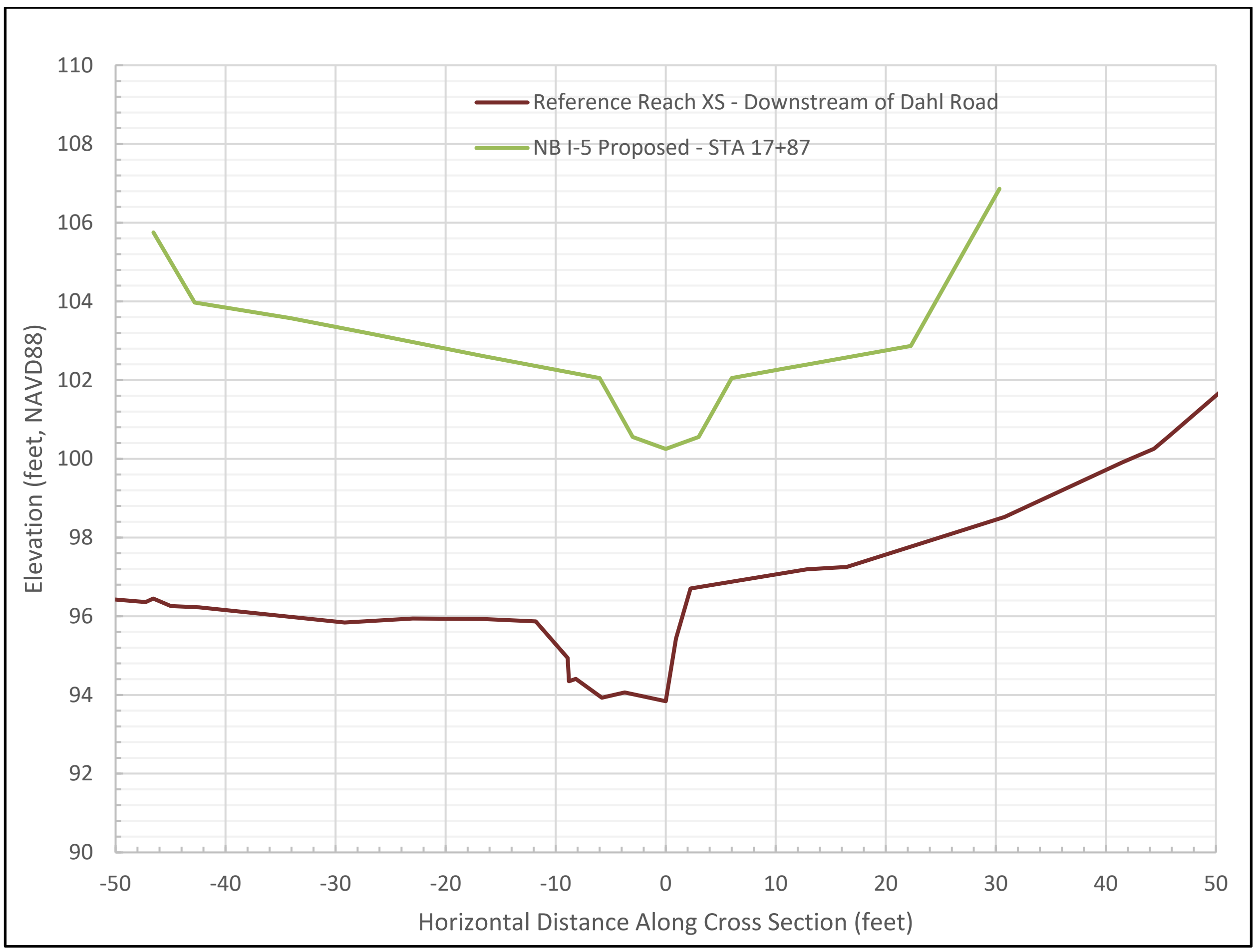


Figure 9.2. Existing and Proposed Channel Cross-sections near the NB I-5 Crossing

9.3 Bed Material

The design intent of the proposed streambed gradation is to produce a streambed material gradation that mimics the natural streambed in terms of median particle size. As discussed in Section 5.0, the average pebble count results from the three pebble counts taken in the reference reach downstream of the NB I-5 crossing will be used as the natural streambed reference material for all crossings. The primary reason for selecting the downstream reference reach as the natural streambed material reference was due to channel gradient similarities between the downstream reach and the proposed reach; the proposed gradient of 1.37 percent is very close to the surveyed gradient of 1.30 percent

The designed streambed gradation was evaluated according to the Modified Shield's methodology as recommended in the WSDOT Hydraulics Manual (WSDOT 2019) and United States Forest Service Stream Simulation Manual for streams under 4 percent gradient. This approach assesses the point of incipient motion for the range of particle sizes in a gradation based on the shear stresses modeled in proposed conditions during the range of design flows. The calculated streambed material gradation is provided in Table 9.1. The average results from the three pebble counts taken in the downstream reference reach are also shown for comparison. Gradation results for all three pebble counts and the design gradation are shown in Figure 9.3.

Table 9.1. Proposed Modified Shield's Gradation

Particle Percent Smaller Than	Proposed Streambed Design (mm) (in)	Pebble Count Average (mm) (in)
D_{16}	2.4 (0.1)	9.9 (0.4)
D_{50}	29.1 (1.2)	32.4 (1.3)
D_{84}	87.1 (3.4)	65.0 (2.6)
D_{100}	140.3 (5.5)	106.0 (4.2)

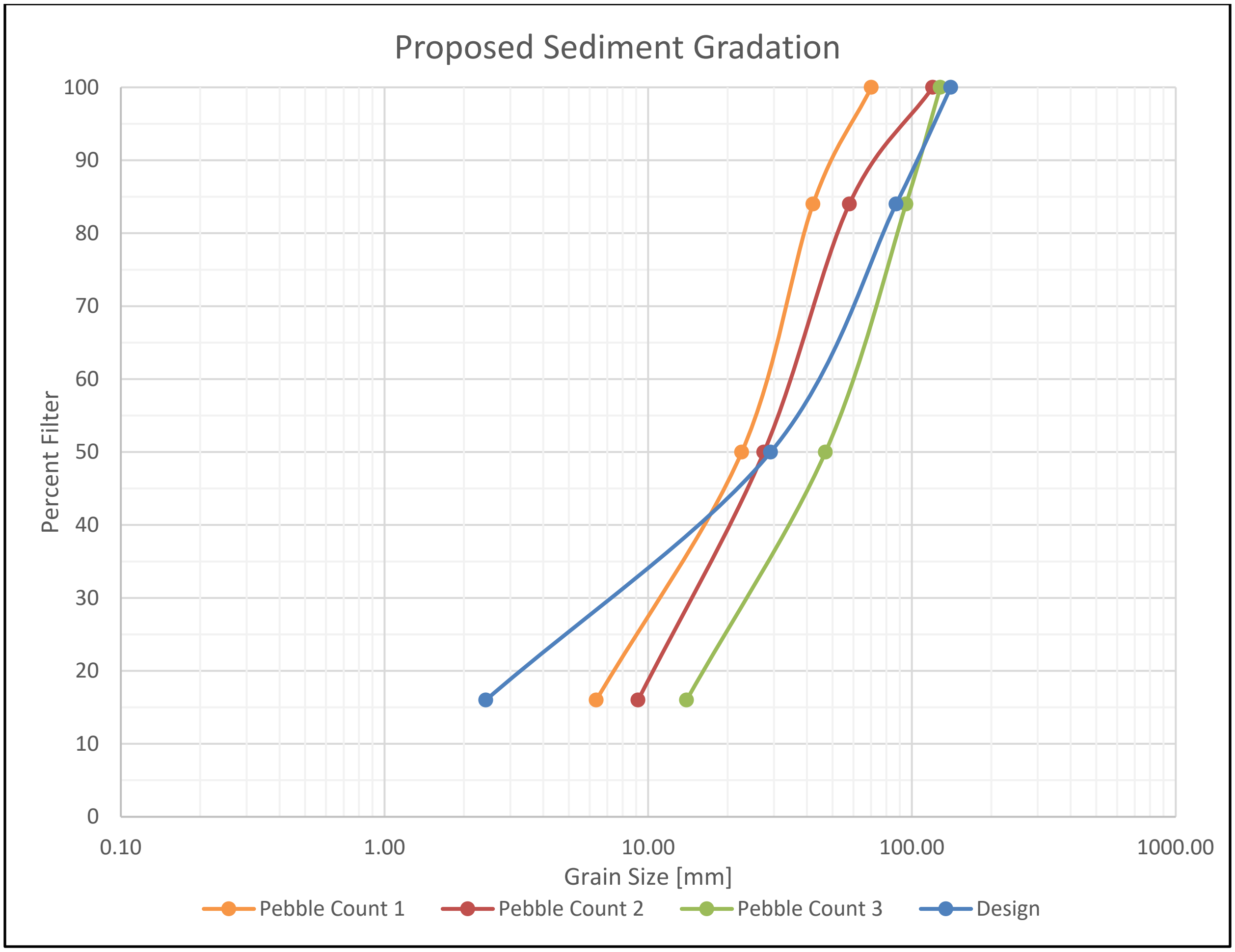


Figure 9.3. Existing and Proposed Streambed Material at the Secret Creek I-5 Crossings

The proposed streambed material should be constructed using WSDOT Standard Specifications for Road, Bridge, and Municipal Construction (WSDOT 2020). The proposed mix consists of 65 percent Streambed Sediment (Section 9-03.11(1)) and 35 percent 6-inch Streambed Cobbles (Section 9-03.11(2)). This gradation results in a D_{50} of 1.2 inches, which is within 20 percent of the average reference reach D_{50} of 1.3 inches. The proposed D_{84} is within 9 percent of the D_{84} of Pebble Count 3 of the design reference reach is therefore within the range of that observed in the reference reach. This streambed sediment composition was chosen because it is the closest gradation possible to satisfy stream simulation criteria while providing the maximum amount of streambed stability. Appendix F contains the Shields analysis.

9.4 Channel Habitat Features

The installation of LWM is proposed throughout both Secret Creek I-5 crossings. The function of the LWM is to add complexity to the system by imitating natural wood recruitment. Following the WSDOT Hydraulics Manual and WDFW Stream Habitat Restoration Guidelines for guidance, the LWM was calculated using Fox and Bolton's 2007 research for selecting the number and size of key pieces reported in the Stream Habitat Restoration Guidelines (Cramer 2012). Based on the guidance, a BFW of 12.1 feet and a proposed stream length of 1,919 feet result in 64 key pieces using the 75th percentile of observed

LWM in unmanaged streams investigated by Fox and Bolton. This meets the recommendation of 0.034 key pieces per foot of stream regrading.

Table 9.2. LWM Metrics

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^{3})
Design	175	415	758.6
Targets	**64**	**222**	**757.6**
	surplus	surplus	surplus

The Stream Habitat Restoration Guidelines also provide guidance on total volume and quantities of all LWM. For streams of this BFW, the 75th percentile of total LWM indicates more than 38 pieces per 100 meters (12 pieces per 100 feet) of channel grading. With a proposed length of grading of 1,925 feet for both NB and SB crossings, this results in the need to place a minimum of 222 total pieces of LWM within the construction limits. The 75th percentile of total LWM volume indicates more than 99 cubic meters per 100 meters (1,066 cubic feet per 100 feet) of channel grading. With a proposed length of grading of 1,925 feet, this results in the need to place a minimum 20,455 cubic feet (757.6 cubic yards) of LWM within the construction limits.

The recommended size of a key piece, based upon BFW, should be a minimum of 1.31 cubic yards. This can be met by a piece approximately 30 feet long by 1.25 feet in diameter. Key pieces should meet the sizing criteria for key pieces reported by Fox and Bolton (2007) and should incorporate root wads for added complexity. The exact configuration and placement will be determined as the design progresses.

The final design must provide stability analyses that reduce the likelihood that adverse impacts to the roadway prism will occur due to the placement of LWM. The final LWM design will follow biomimicry concepts to provide fish habitat similar to that encountered in the reference reach. Preformed scour pools are to be included at stream meanders in the final stream design and may be designed in conjunction with some LWM features. LWM should be included across the floodplain and should include channel spanning wood, since extensive channel spanning wood was observed in the existing condition. The addition of smaller wood will be necessary as well, and slash should be incorporated into the floodplain bed material. Given the large vertical and horizontal clearance provided by the proposed bridge structures relative to the stream size, LWM underneath the bridge is likely feasible and should be included if approved by HQ Hydraulics. Additionally, the design must include bioengineering for bank stability immediately following construction; design coordination with the landscape architect's office is required.

10.0 Floodplain Changes

Due to expansion of the floodplain through the crossing relative to the existing conditions, floodplain storage is expected to increase. No net fill will be added to the floodplain. The elimination of the existing culvert will remove the backwater effect upstream, reducing upstream water surface elevations, and no changes in water surface elevations downstream of the project limits are expected.

11.0 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its built structures. As such, the agency approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. For bridges and buried structures, the greatest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

11.1 Climate Resilience Tools

Climate resilience is evaluated at each crossing using the Climate Impacts Vulnerability Assessment Maps that WSDOT created to assess risk level of infrastructure across the state (WSDOT 2011). The NB I-5 Secret Creek crossing has been evaluated, and it has been determined to be a high-risk site based on the Climate Impacts Vulnerability Assessment Maps.

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program for the year-2080 scenario. Appendix G contains the projections received from WDFW for the project site. The 100-year flow event was chosen to be evaluated because, as it is an extreme event, if the channel behaves similarly through the structure during this event as it does the adjacent reaches, then it is anticipated that this relationship would be true at lower flows as well.

11.2 Hydrology

For each design, WSDOT uses the best available science to assess site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgement is used to compare model results to system characteristics. If there is significant variation, then the hydrology is reevaluated to determine whether adjustments must be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 projected 100-year flow event to check for climate resiliency. The design flow for the crossing is 278 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 27.6 percent, yielding a projected 2080 flow rate of 354.7 cfs.

11.3 Structure Width

Analyzing velocity ratios, the minimum structure width was determined to be 40 feet for reasons discussed in Sections 8.0 and 9.0. This structure width was evaluated at the 100-year flow event and the projected 2080 100-year-flow event, and it was determined that it would produce similar velocities through the structure and adjacent reaches. The velocity comparisons for these flow rates can be seen in Table 8.1.

As the climate resiliency flows produce similar velocities and minimal changes upstream, downstream, and through the structure, it is recommended that the structure width does not have to be increased. As the velocities did not significantly change, neither did the velocity ratios.

11.4 Freeboard and Countersink

The minimum required freeboard at this location is 3 feet at the 100-year flow event based on BFW. The water surface elevation is projected to increase by up to 0.5 foot for the 2080 projected 100-year flow to 105.4 feet at the proposed crossing inlet. This provides 27.6 feet of freeboard for the 100-year flow with a 10-foot structure thickness. The minimum freeboard at this site is recommended to be increased to accommodate climate resilience, resulting in a recommended 3.5 feet of freeboard over the current 100-year water surface elevation due to the projected increase in water surface elevation. In addition, 10 feet of clearance should also be provided over the channel thalweg. Achieving minimum freeboard and clearance requirements is not expected to be a problem at this site.

11.5 Summary

A minimum hydraulic opening of 40 feet and a minimum freeboard of 3.5 feet over the current 100-year water surface elevation will allow for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2080 100-year flow event. Additionally, a minimum 10 feet of clearance between the channel bottom and the low chord of the crossing structure should be provided. This will help ensure that the structure is resilient to climate change and that the system can function naturally, including the passage of sediment, debris, and water in the future.

References

Arneson, L.A., L.W. Zevenbergen, P.F. Lagasse, W.J. Spitz. (2012). *Stream Stability at Highway Structures – Fourth Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication No. FHWA-HIF-12-004, (HEC No. 20).

Barnard, R.J., et al. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Bureau of Reclamation. SRH-2D – Sedimentation and River Hydraulics Version 3. June 2019.

Chow, V.T., 1959, Open Channel Hydraulics, McGraw-Hill book Company, New York.

Cramer, Michelle L. (managing editor). 2012. Stream Habitat Restoration Guidelines. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service. Olympia, Washington.

Department of Natural Resources (DNR). 2000. Geologic Map of the Suquamish 1:100,000 Quadrangle, Washington.

Ecology (Washington State Department of Ecology). 2020. Water Quality Atlas. Available at https://fortress.wa.gov/ecy/waterqualityatlas/map.aspx. Accessed on January 17, 2020.

ESRI. World Imagery. Accessed May 1, 2020. Available at https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9.

FHWA (Federal Highway Administration). 2019. HY-8 Culvert Hydraulic Analysis Program Version 7.60. July 30, 2019. Available at https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/.

Mastin, M.C., C.P. Konrad, A.G. Veilleux, and A.E. Tecca. 2016. Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014 (version 1.2, November 2017). U.S. Geological Survey Scientific Investigations Report 2016-5118.

MGS Engineering Consultants, Inc. 2018. MGS Flood – Continuous Hydrologic Model for Stormwater Facility Design V4. 2018. Available at http://www.mgsengr.com/mgsfloodhome.html.

Miller, C. and D. Somers. 1989. TFW Stillaguamish river early action project. Tulalip Tribes Natural Resources Department, Marysville, Washington.

NRCS, Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for [Snohomish County, WA]. Available online. Accessed on May 26, 2020.

Quantum Spatial. (2017). Western Washington 3DEP LiDAR Technical Data Report. Provided by Washington Department of Natural Resources.

SIRC (Stillaguamish Implementation Review Committee). 2005. Stillaguamish Watershed Chinook Salmon Recovery Plan. Published by Snohomish County Department of Public Works, Surface Water Management Division. Everett, Washington.

Soar, P., and C. Thorne. 2001. Channel Restoration Design for Meandering Rivers. 454.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, Oregon. Available from the National Marine Fisheries Service, Portland, Oregon.

SWIFD. 2020. State-Wide Integrated Fish Distribution Web Map. Available at https://geo.nwifc.org/swifd/. Accessed on March 18, 2020.

United States Department of Agriculture. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring.

United States Department of Agriculture, Forest Service(USFS). 2008. Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, Appendix E. San Dimas, California.

United States Geological Survey. 2014. “StreamStats in Washington.” Available at http://water.usgs.gov/osw/streamstats/Washington.html. Accessed October 22, 2019.

WDFW (Washington Department of Fish and Wildlife). 2008. Priority Habitat and Species List. Olympia, Washington. 292pp.

WDFW (Washington Department of Fish and Wildlife). 2019. WDFW Fish Passage and Diversion Screening Inventory Database. Level A Culvert Assessment Report for Site ID 990622. Available at http://apps.wdfw.wa.gov/fishpassagephotos/Reports/990622_Report.pdf.

WDFW (Washington Department of Fish and Wildlife). 2020. WDFW Fish Passage and Diversion Screening Inventory Database. Available at https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html.

WDFW and WWTIT (Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes). 1994. 1992 Washington state salmon and steelhead stock inventory. Appendix 1: Puget Sound Stocks: North Puget Sound Volume, Olympia, Washington.

Washington State Department of Transportation (WSDOT). April 2019. Hydraulics Manual M 23-03.06. Available at https://www.wsdot.wa.gov/Publications/Manuals/M23-03.htm.

WSDOT. 2011. Climate Impacts Vulnerability Assessment. Washington State Department of Transportation, Olympia, WA. Available at https://www.wsdot.wa.gov/sites/default/files/2011/07/28/Climate-Impact-AssessmentforFHWA-12-2011.pdf

WSDOT. 2020. Standard Specifications for Road, Bridge, and Municipal Construction. Washington State Department of Transportation, Olympia, WA. Publication Number M 41-10. Available at https://www.wsdot.wa.gov/publications/manuals/fulltext/M41-10/SS.pdf.

WSCC (Washington State Conservation Commission). 1999. Salmon Habitat Limiting Factors Final Report. Water Resource Inventory Area 5 Stillaguamish Watershed. July 1999. 83 pp.

Appendices

Appendix A – WSDOT Field Report

Appendix B – FEMA FIRM Map

Appendix C – SRH-2D Existing Conditions Model Results

Appendix D – SRH-2D Proposed Conditions Model Results

Appendix E – Preliminary Stream Plan, Profile, Details Sheets

Appendix F – Streambed Material Sizing Calculations

Appendix G – WDFW Future Projections for Climate-Adapted Culvert Design Printout

Appendix A

WSDOT Field Report

This Page Intentionally Left Blank

Hydraulics Field Report

Hydraulics Section

Project Number:	XL5949
Project Name:	I-5 Northbound Secret Creek to Pilchuck Creek Fish Barrier Removal PHD
Date:	3/20/2020
Project Office:	Mount Vernon Project Engineer's Office
Time of Arrival:	10:05 am
Location:	I-5 Northbound MP 211.7 Crossing of Secret Creek
Time of Departure:	4:00 pm
Purpose of Visit:	Site recon – BFW measurements
Weather:	Sunny, clear
Prepared By:	T. Nabours
Meeting Location:	Dahl Road near crossing location

Attendance List:

Name	**Organization**	**Role**
Tyler Nabours	Parametrix	Hydraulics/Hydrology – PHD
Theo Prince	Parametrix	Hydraulics/Hydrology – PHD
Steve Krueger	Parametrix	Fisheries Biologist

Bankfull Width:

During a 3/20/2020 field visit conducted by Parametrix, bankfull width measurements were obtained. Upstream of structure WDFW ID 990622, measurements were taken at 40 feet, 110 feet, and 225 feet upstream of culvert inlet, and average 9.3 feet in width. The stream has been highly modified with large rock and sheet metal bank armoring

The culvert is the Northbound I-5 culvert is identified as WDFW Site ID 990622. Another culvert (WDFW Site ID 05.0065 0.64 and is located downstream of the NB I-5 culvert at Dahl Road. No BFW measurements were taken in the reach between the two culverts.

Approximately 150 feet downstream of the Dahl Road culvert begins a selected reference reach for the project. Bankfull widths in the reference reach were taken at 105 feet, 119 feet, 127 feet, 180 feet, 229 feet, and 253 feet downstream of the upstream beginning of the reference reach. These values give an average bankfull width of 12.0 feet.

No stakeholder field visit has been conducted to review these results and reach agreement on BFW. A separate Field Report has been produced to document field visits to the SB I-5 crossing (WDFW Site ID 990623). The average of all BFW measurements documented in the Field Report for the NB I-5 crossing is 12.0 feet.

Reference Reach:

The reference reach begins about 1500 feet downstream of the Dahl Road culvert outlet (Figure 1), or 85 feet downstream of the Dahl Road culvert outlet for gradient description purposes in the PHD. This reach exhibits a typical pool riffle morphology. The streambed is primarily coarse gravel. Signs of channel migration including bank undercutting, gravel bars, and high-flow paths were observed. Moderate presence of LWM was recorded in the reference reach.

Source: ESRI, WSDOT, StreamStats, WA DNR, Snohomish County

Secret Creek Culverts I-5
Potential Reference Reach Area
Watercourse

0 125 250 500 Feet

Figure 2.1 Project Area
Secret Creek

Snohomish County, WA

Figure 1. Site Map

Data Collection:

The primary site investigation was conducted on 3/20/2020 by Theo Prince (hydraulics and hydrology engineer), Steven Krueger (fisheries biologist), and Tyler Nabours (hydraulics and hydrology engineer) from Parametrix. The team recorded site observations and measurements at the crossings, downstream approximately 500 feet past the Dahl Road Culvert, between the Dahl Road and I-5 NB Culvert, and approximately 200 feet upstream of the I-5 Northbound culvert inlet. The collection of data included site photographs, bankfull width measurements, record of LWM in channel and recruitment potential, pebble counts, fish habitat assessment, record of pool and riffle/step dimensions if applicable, record of rocks and other key features, and records of overbank vegetation and soil types.

Observations:

Distance **Upstream** of Culvert WDFW ID 990622 (I-5 NB)

meters	feet	Notes
0	0	Culvert Inlet - 8' ϕ (Photo 1)
12.2	40	BFW = 8.5 feet. LWM 5-pieces above, channel spanning, 10-inch diam, 10-inch diam, 8-inch diam, 12-inch diam, 30-inch diam. (Photo 2)
33.5	110	BFW = 9.5 feet, approximately 110-feet upstream of I-5 NB culvert. (Photo 3)
53.4	175	Upstream cemented substrate, straight section, log weir
68.6	225	BFW = 9.9-feet (Photo 4)

Distance **Downstream** of Culvert WDFW ID 990622 (I-5 NB)

meters	feet	Notes
0.0	0	Downstream end of I-5 NB culvert, 8-foot rise, 8.5-foot span, CMP with steel plate weirs, space 17.8-foot ea (14 total). Invert downstream of weirs has eroded through the pipe with approx 3.5' from weir to scour hole bottom and approx. 6-inch of drop over each weir. Outlet has concrete apron with low-flow notch in v-shaped weir, 4-foot of scour at outlet of concrete weir. (Photo 1, Photo 2)
0 to 13.7	0 to 45	24-inch to 36-inch rip rap, banks on both sides. (Photo 3)
8.5	28	90-degree bend to left, gravel bar LB. (Photo 4)
12.2	40	Log weir 18-inch diam., notched, pinned, and anchored with 3-man rock both sides. 3-foot from weir to bottom of scour hole, 5-inch drop in water surface over weir. First in a series of 4 similar. (Photo 5)
18.3	60	Log weir, 3-foot from weir to bottom of scour hole, 6-inch drop in water surface over weir. (Photo 5)
24.4	80	Log weir, 3.5-foot from weir to bottom of scour hole, 10-inch drop in water surface over weir. (Photo 5)
31.1	102	Log weir, 8-inch from weir to bottom of scour hole, 2-inch drop in water surface over weir.
37.2	122	Log weir, 3-foot from weir to bottom of scour hole, 6-inch drop in water surface over weir.
41.2	135	12-inch diam. LWM x 20-foot long. 4-inch diam. MWM x 20-foot long. (Photo 6)
43.3	142	Squash pipe CMP, 8.5-foot span, 6.5-foot rise. (Photo 7)

Reference Reach - Distance Downstream from Beginning of Reference Reach (Reference reach begins ~250 feet downstream of Dahl Road Culvert Outlet)

meters	feet	Notes
0.0	0	LWM, 10-inch diameter, 30-foot long.
4.27-12.5	14-41	Pebble Count #3 (renamed #1 in PHD) at riffle, upstream of beaver dam pool. (Photo 1)
9.7	32	Bottom of riffle.
13.4	44	Bend at US end of pool 3 to 4-foot pool depth, 3-foot depth to floodplain. 12-inch to 18-inch LWM in pool, 10-foot long
21.9	72	16-foot wide pool upstream of beaver dam. (Photo 2)
27.1	89	Plunge pool DS of beaver dam, 3-feet from top of dam to bottom of pool. 1.25-foot drop in WS over beaver dam with pool behind dam.
32.0	105	BFW measurement, 11-feet
34.1	112	Pebble Count #1 (renamed #2 in PHD) (Photo 3).
36.3	119	BFW measurement, 8-feet, bank full depth 2.25-feet, banks w/ undercutting.
38.7	125	Begin bend.
39.9	127	BFW measurement, 10.2-feet. (Photo 4)
44.5	146	12-inch diam. LWM, 30-feet long with root wad engaged, RB. (Photo 5)
51.5	169	LWM, 10 to 12-inches diameter, 6-feet long.
48.8 to 52.1	160 to 171	Riffle Section.
53.0	174	LWM, 8-inch diameter, 20-feet long. (Photo 6)
52.7 to 56.7	173 to 186	Pool (Photo 7)
54.9	180	BFW = 15-feet at pool, 2-foot depth to floodplain. (Photo 8)
56.7	186	LWM on RB with debris pile. (Photo 9)
58.8	193	LWM, 8-inch diameter, 10-feet long. (Photo 10)
59.5	195	LWM, 10-inch diameter, 25-feet long. (Photo 10)
62.2	204	Pebble Count #2 (renamed #3 in PHD). (Photo 11)
65.5	215	LWM buried in bed, unknown diameter and length
62.2 to 65.9	204 to 216	Corner pool, LB. (Photo 12)
65.9 to 70.7	216 to 232	Run and glide.
69.8	229	BFW = 13.9-feet, Max depth = 1.5-feet. (Photo 13)
70.7 to 77.7	232 to 255	Riffle Section
77.1	253	BFW = 13.7-feet, max depth 1.9-feet. (Photo 14)
79.6	261	LWM, 24-inch diameter, 12-feet long. (Photo 15)
79.6 to 84.8	261 to 278	Lateral scour pool (Photo 15)
81.4	267	Gravel bar (Photo 15)
87.8 to 90.2	288 to 296	mid-channel pool
88.1	289	LWM weir with plunge pool, 10-inch diameter, 15-feet long. (Photo 16)
93.3	306	RB 2 to 3.5-foot diameter boulders, clay exposed in bottom of channel. (Photo 17)

Pebble Counts/Sediment Sampling:

Pebble counts were conducted during the 3/20/2020 site visit. All three pebble counts were performed in the reference reach downstream of the Dahl Road Culvert. The three pebble counts show that the bed material is primarily medium and coarse gravel (Figure 2).

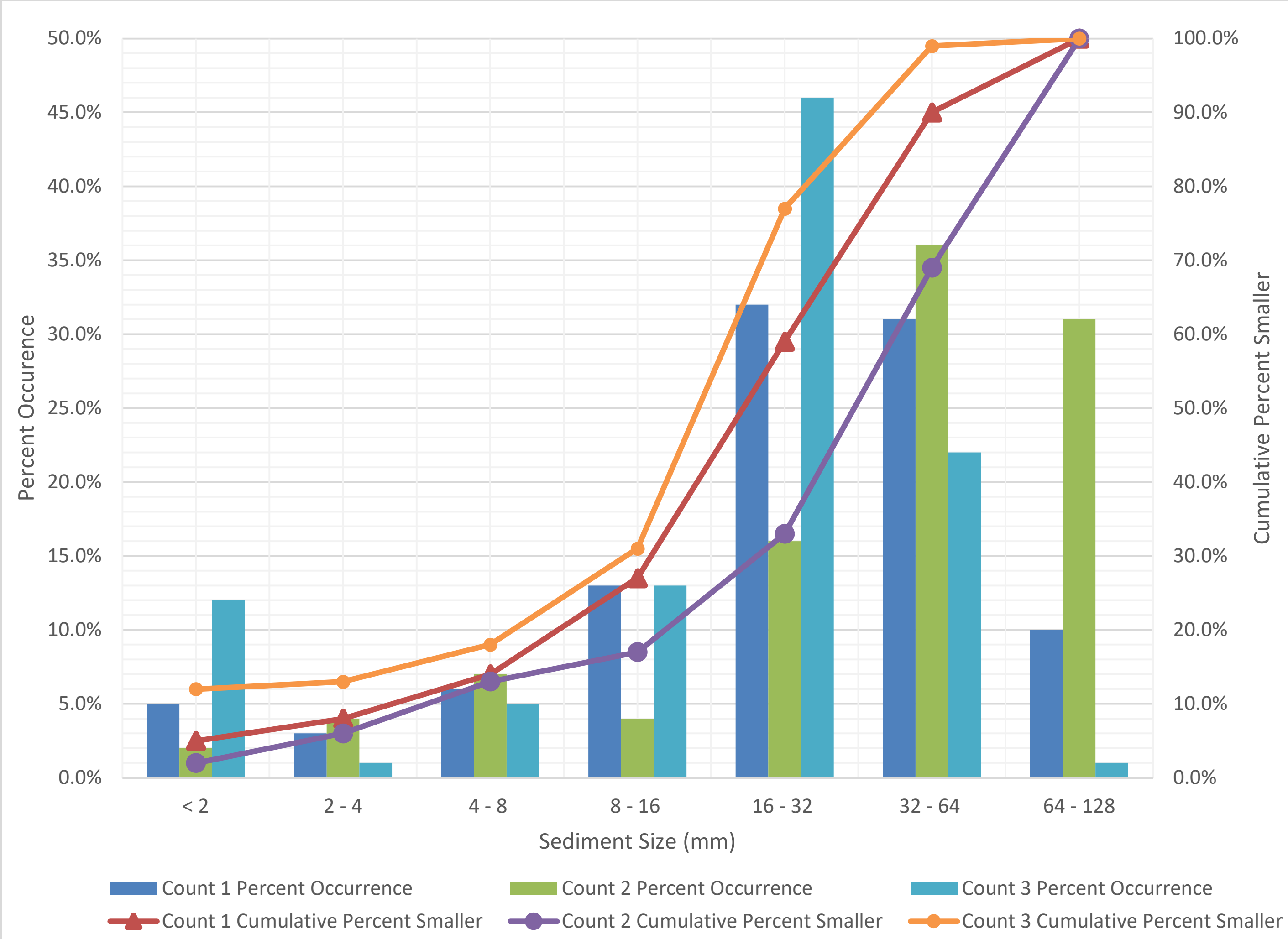


Figure 2. Sediment Properties in Reference Reach Downstream of NB I-5 Crossing

Photos:

Photographs in Attachments A, B, and C are referenced in site observations.

Attachment A –

Photographs Upstream of I-5 NB Culvert - WDFW Barrier ID 990622

Photo 1 – I-5 NB Culvert Inlet WDFW ID 990622

Photo 2 – 40 feet Upstream of I-5 NB Culvert, LWM Jam, BFW=8.5 feet

Photo 3 – 110 feet Upstream of Culvert WDFW ID 990622, BFW=9.5 feet

Photo 4 – 225 feet Upstream of Culvert WDFW ID 990622, BFW=9.9 feet

Attachment B –

Photographs Downstream of I-5 NB Culvert, Upstream of Dahl Road Culvert - WDFW Barrier ID 990622

Photo 1 – Looking US into Culvert WDFW ID 990622, I-5 NB Culvert

Photo 2 – Outlet of Culvert WDFW ID 995265

Photo 3 – 24-36 inch Rip-Rap on RB

Photo 4 – 90 Degree bend to the left, Gravel bar on LB

Photo 5 – Log Weirs at 40, 60, and 80 feet downstream.

Photo 7 – Inlet of Dahl Road Culvert, WDFW Barrier ID 990622

Photo 6 – LWM at 135 feet Downstream

Attachment C –

Photographs Downstream of Dahl Road Culvert - WDFW Barrier ID 990622

Photo 1 – Pebble Count #3 Riffle Section 14-41 feet Downstream

Photo 2 – 16ft Wide Pool Upstream of Beaver Dam, 72 feet downstream

Photo 3 - Pebble Count #1 at 112 feet downstream

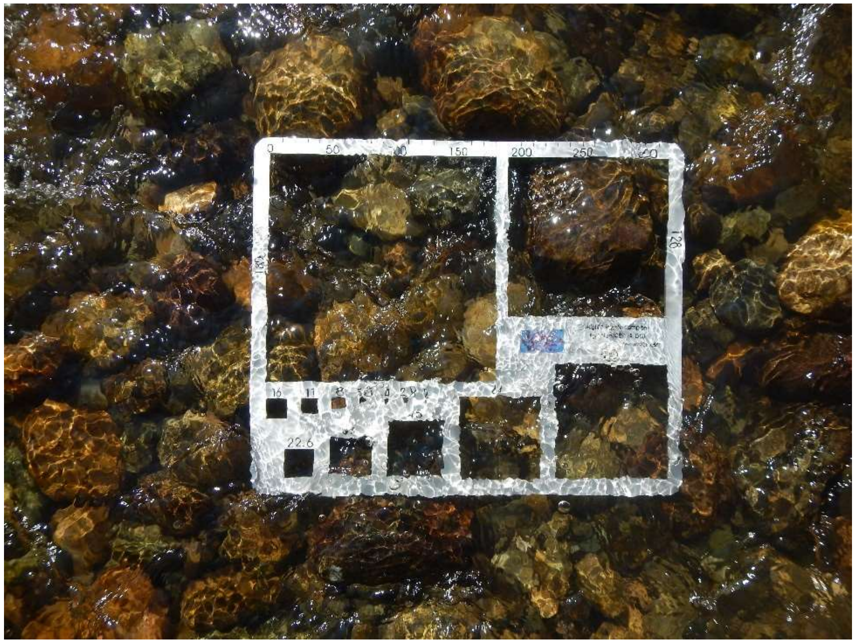


Photo 4 –119 Feet Downstream BFW Measurement=8 feet

Photo 5 –127 Feet Downstream BFW Measurement=10.2 feet

Photo 6 – 12-inch, 30-foot LWM, 146 feet downstream

Photo 7 – 8-inch, 20-foot LWM at 174 feet downstream

Photo 8 – Large Pool at 173 to 186 feet downstream, BFW=15 feet

Photo 9 – LWM Debris Pile on RB at 186 feet downstream

Photo 11 – Pebble Count #2 at 204 feet downstream

Photo 10 – LWM at 195 feet Downstream

Photo 12 – Corner Pool on LB at 204 to 216 feet downstream

Photo 13 – 229 feet downstream, BFW Measurement=13.9 feet

Photo 14– 253 feet downstream, BFW Measurement=13.7 feet

Photo 15 – 24-inch, 12-foot LWM at 261 feet downstream, Lateral Scour Pool and Gravel Bar

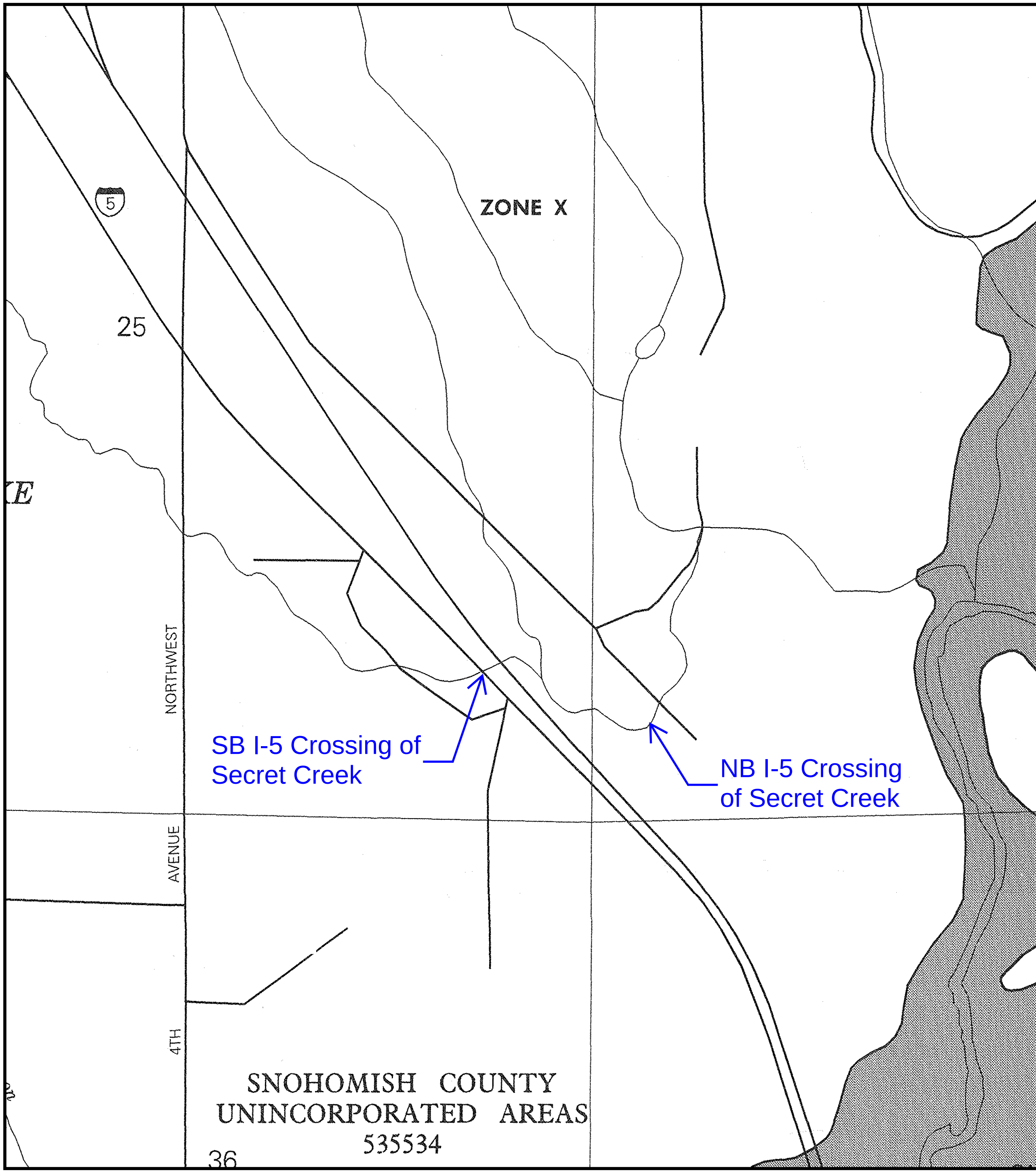
Photo 16 – 10-inch, 15-foot LWM Weir at 289 feet downstream

Photo 17 – Two 3.5-foot diameter boulders on RB

Appendix B

FEMA FIRM Map

This Page Intentionally Left Blank



NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

SNOHOMISH COUNTY, WASHINGTON AND INCORPORATED AREAS

PANEL 380 OF 1575

(SEE MAP INDEX FOR PANELS NOT PRINTED)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SNOHOMISH COUNTY, UNINCORPORATED AREAS	535534	0380	E

MAP NUMBER
53061C0380 E

EFFECTIVE DATE:
NOVEMBER 8, 1999

Federal Emergency Management Agency

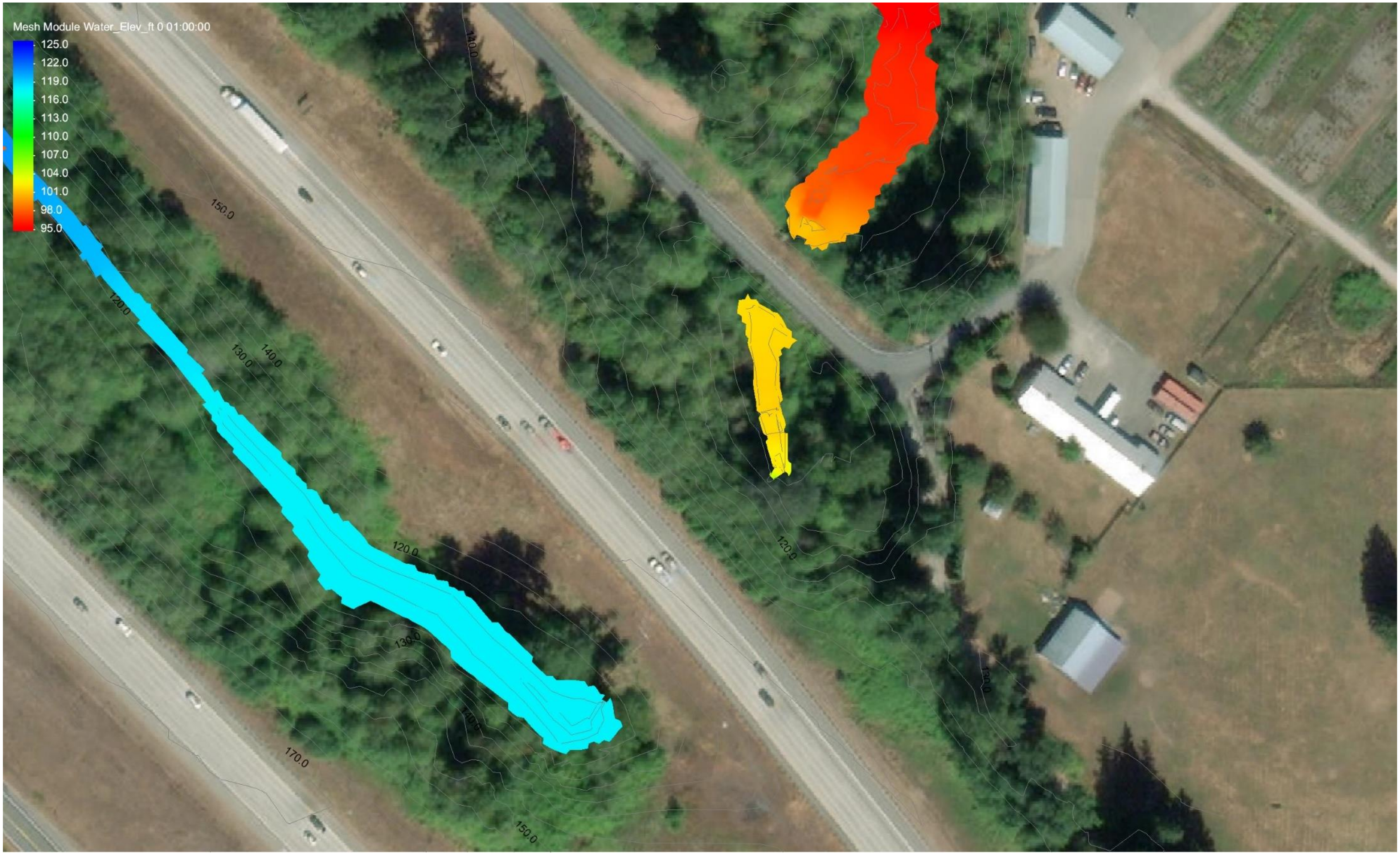
This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

This Page Intentionally Left Blank

Appendix C

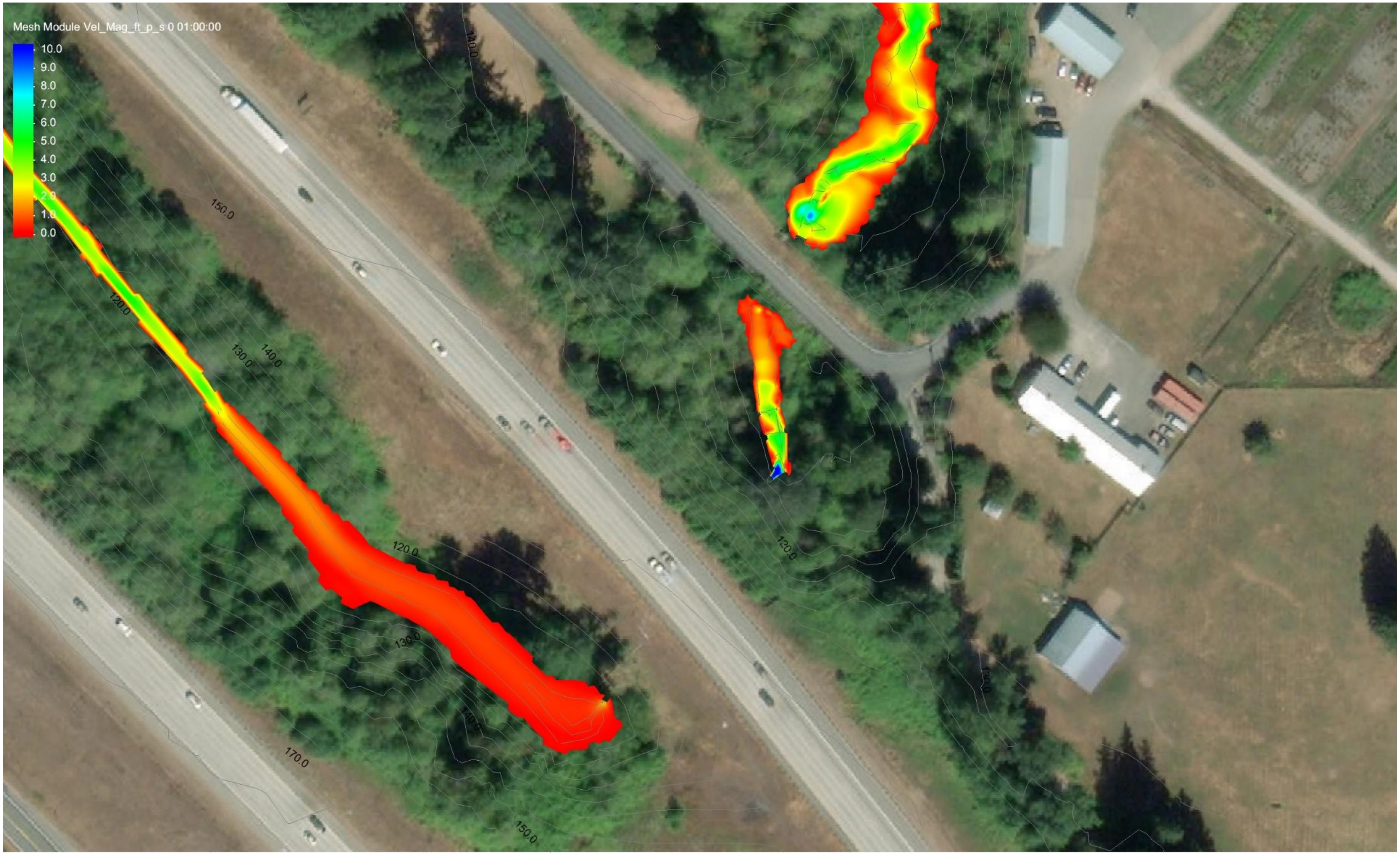
SRH-2D Existing Conditions Model Results

This Page Intentionally Left Blank



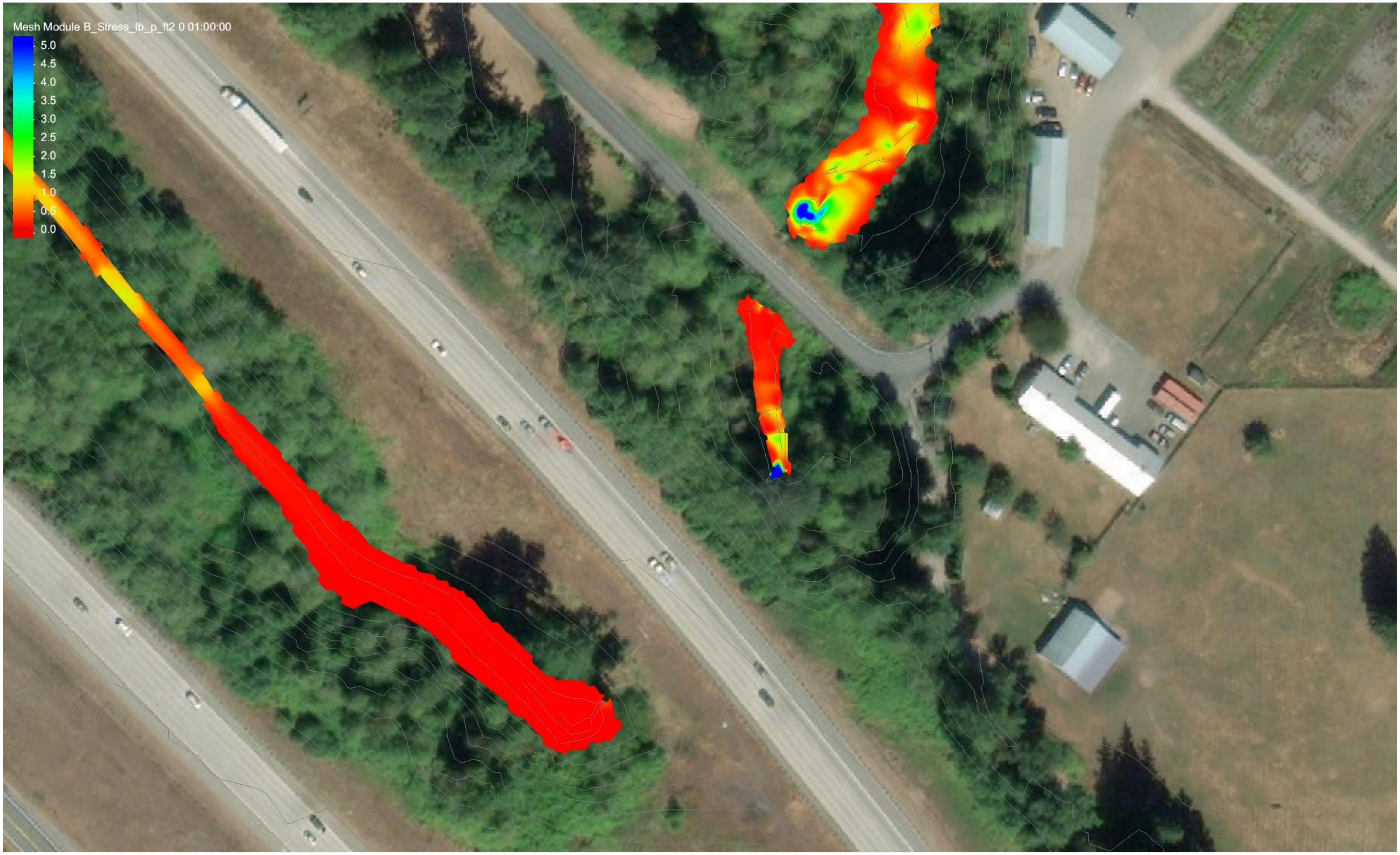
Parametrix

Figure A.1.1
Secret Creek at I-5 Northbound
2-Year Water Surface Elevation



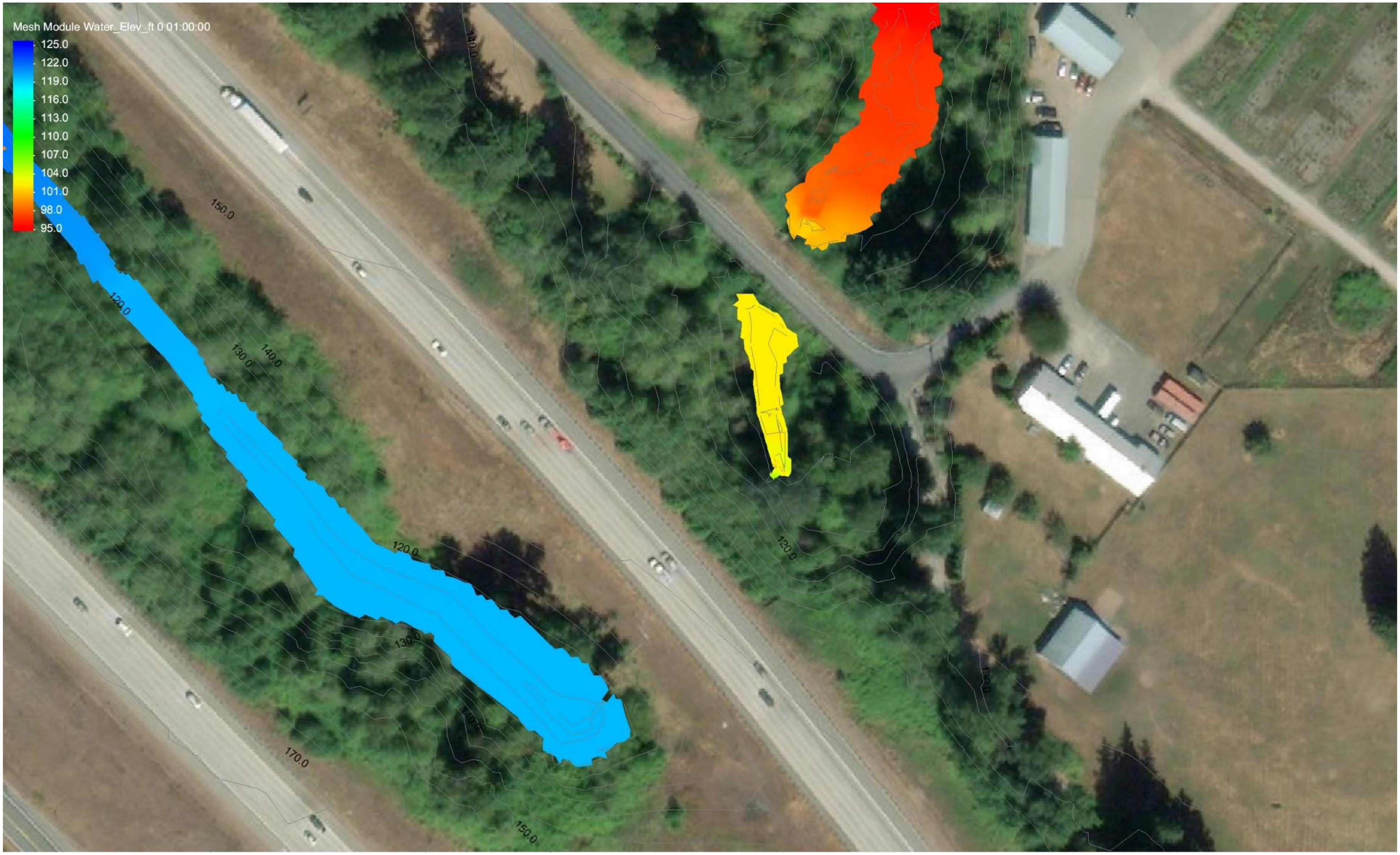
Parametrix

Figure A.1.2
Secret Creek at I-5 Northbound
2-Year Velocity



Parametrix

Figure A.1.3
Secret Creek at I-5 Northbound
2-Year Shear Stress

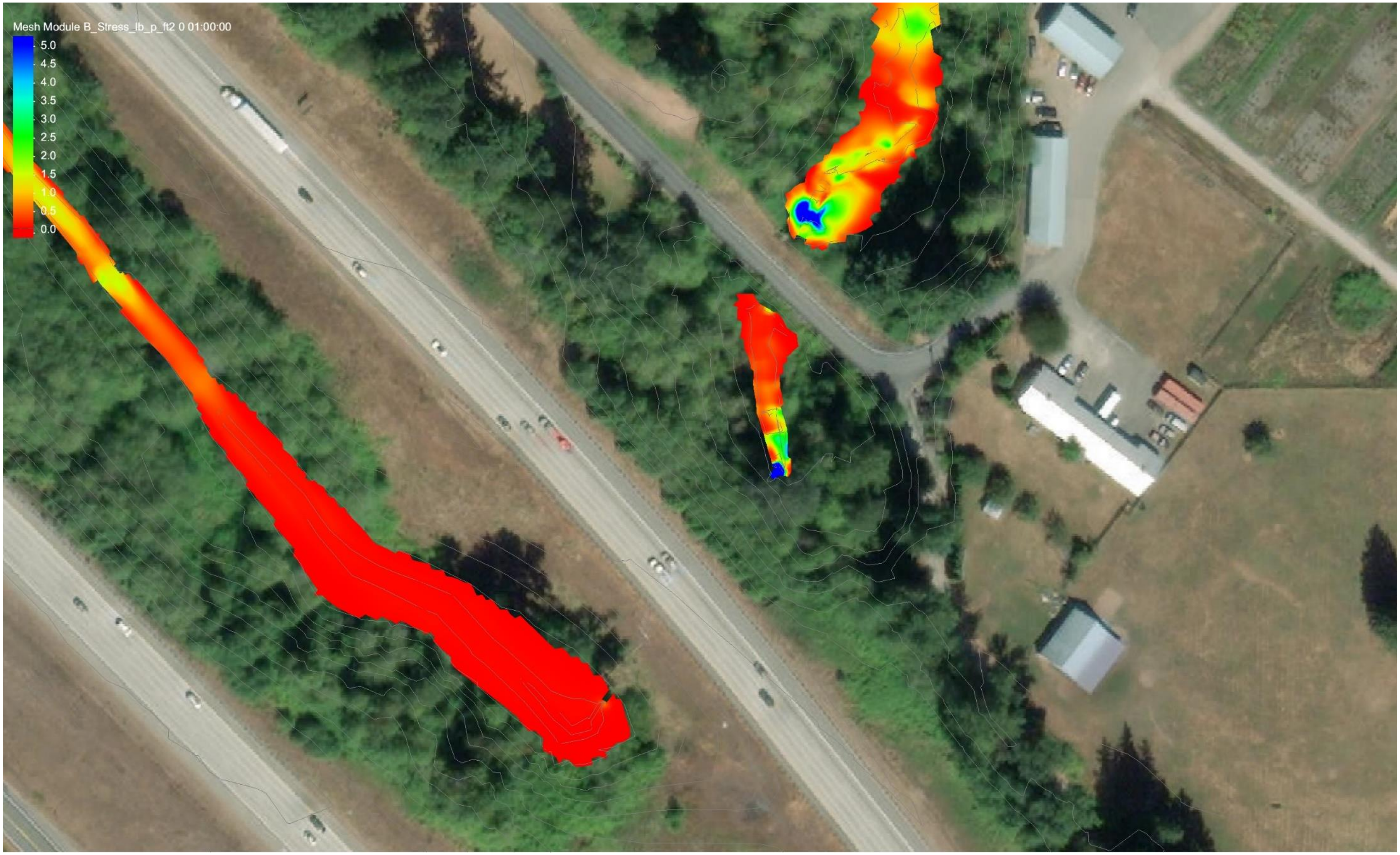


Parametrix

Figure A.1.4
Secret Creek at I-5 Northbound
25-Year Water Surface Elevation

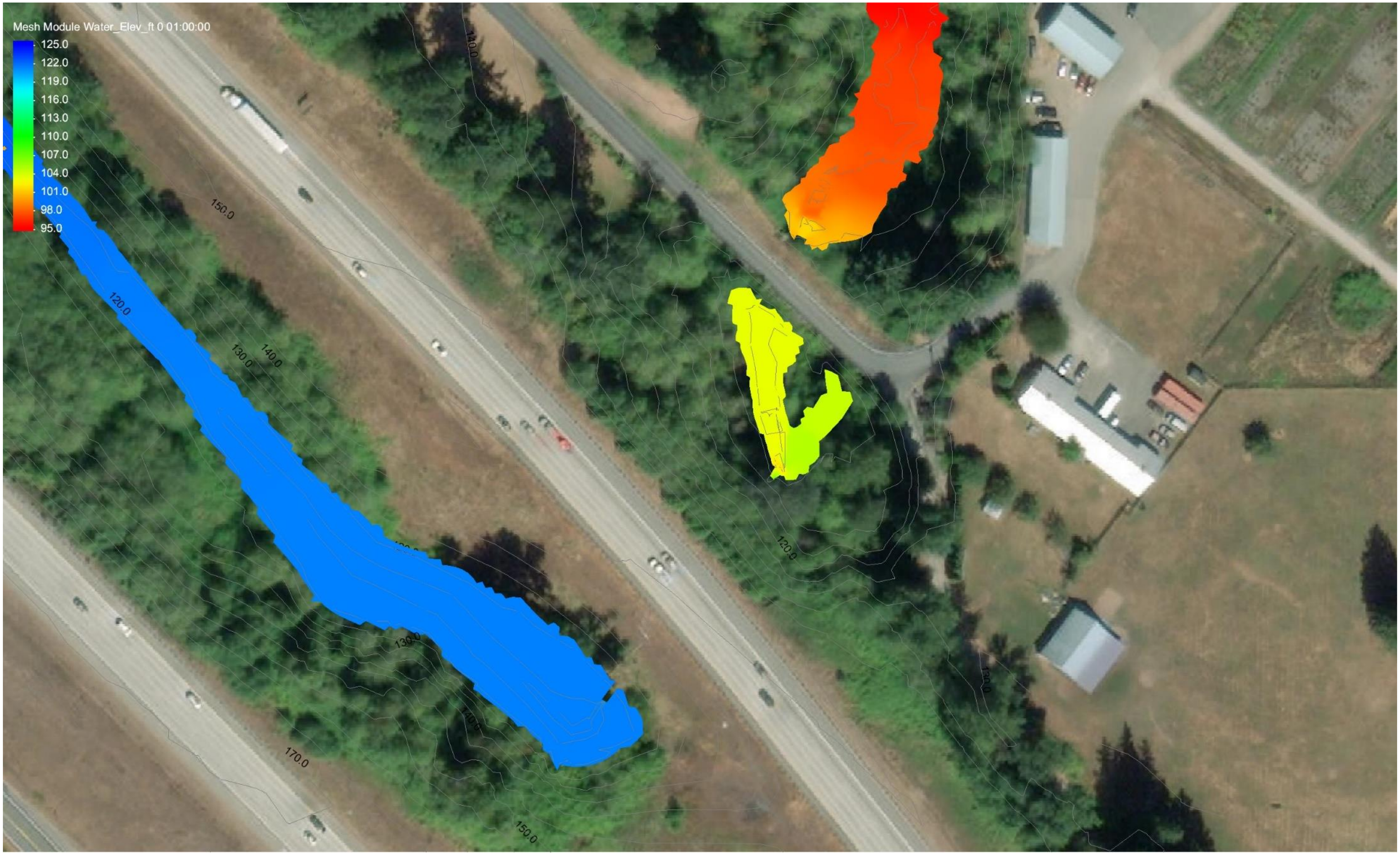
Parametrix

Figure A.1.5
Secret Creek at I-5 Northbound
25-Year Velocity



Parametrix

Figure A.1.6
Secret Creek at I-5 Northbound
25-Year Shear Stress



Parametrix

Figure A.1.7
Secret Creek at I-5 Northbound
100-Year Water Surface Elevation

Parametrix

Figure A.1.8
Secret Creek at I-5 Northbound
100-Year Velocity

Parametrix

Figure A.1.9
Secret Creek at I-5 Northbound
100-Year Shear Stress

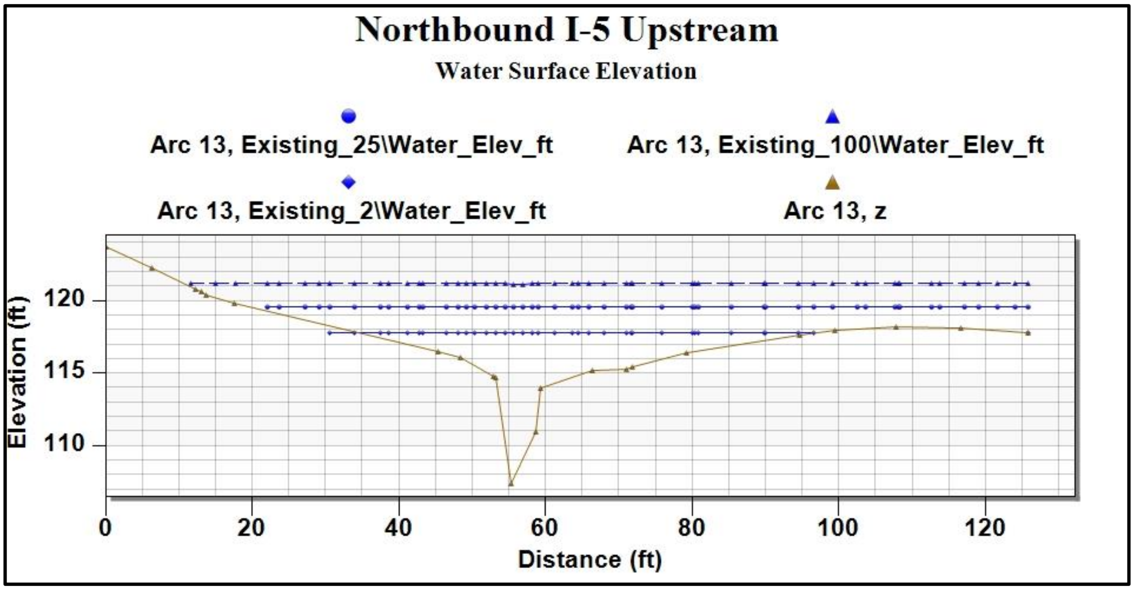


Figure A.2.1
Secret Creek at I-5 Northbound

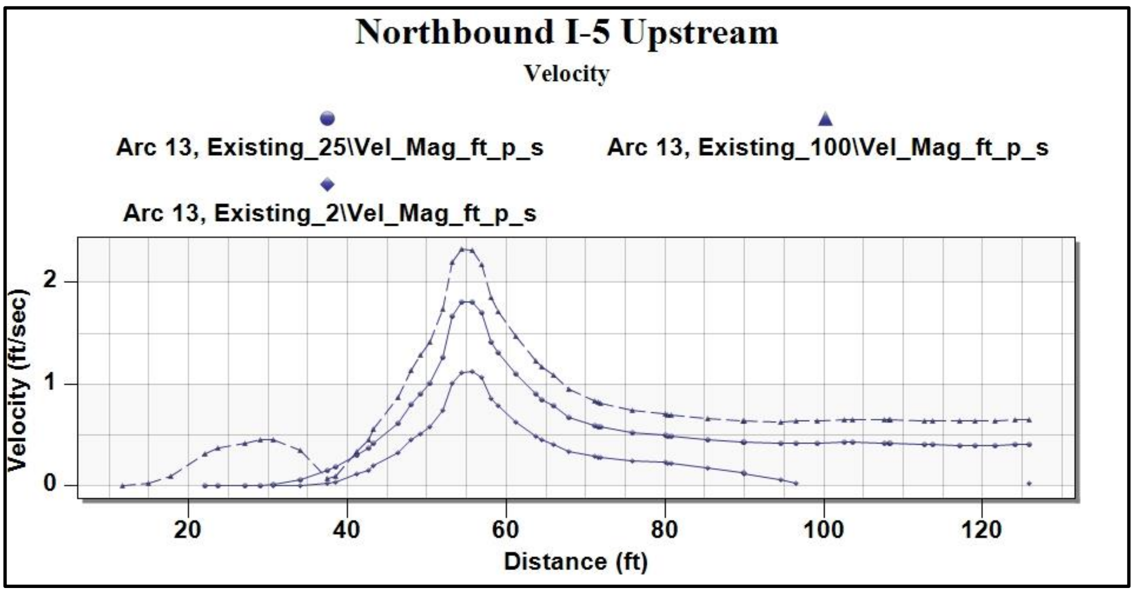


Figure A.2.2
Secret Creek at I-5 Northbound

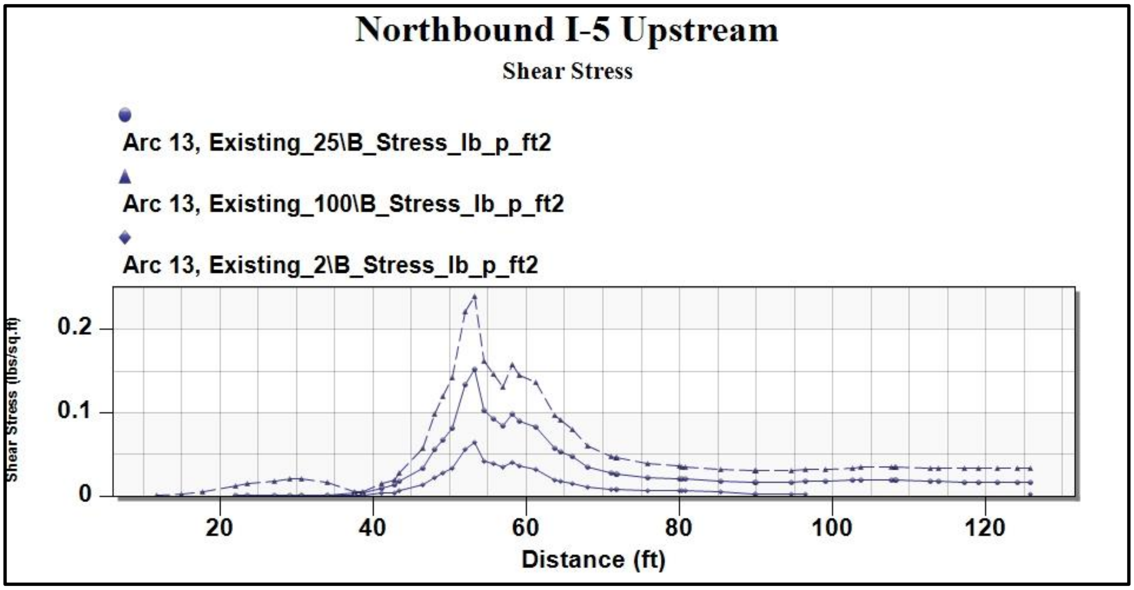


Figure A.2.3
Secret Creek at I-5 Northbound

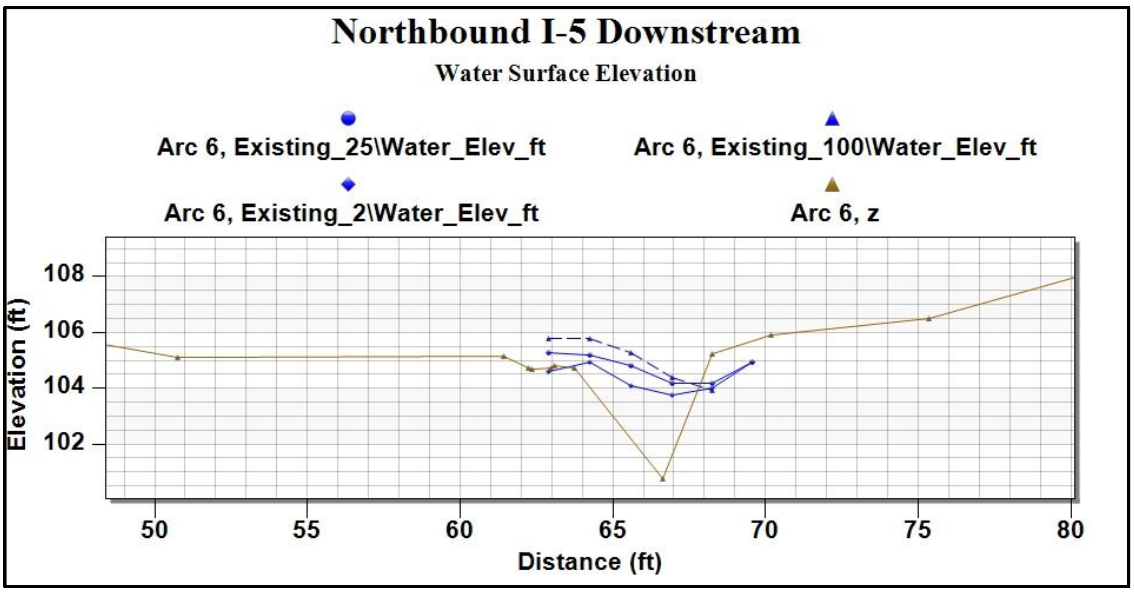


Figure A.2.4
Secret Creek at I-5 Northbound

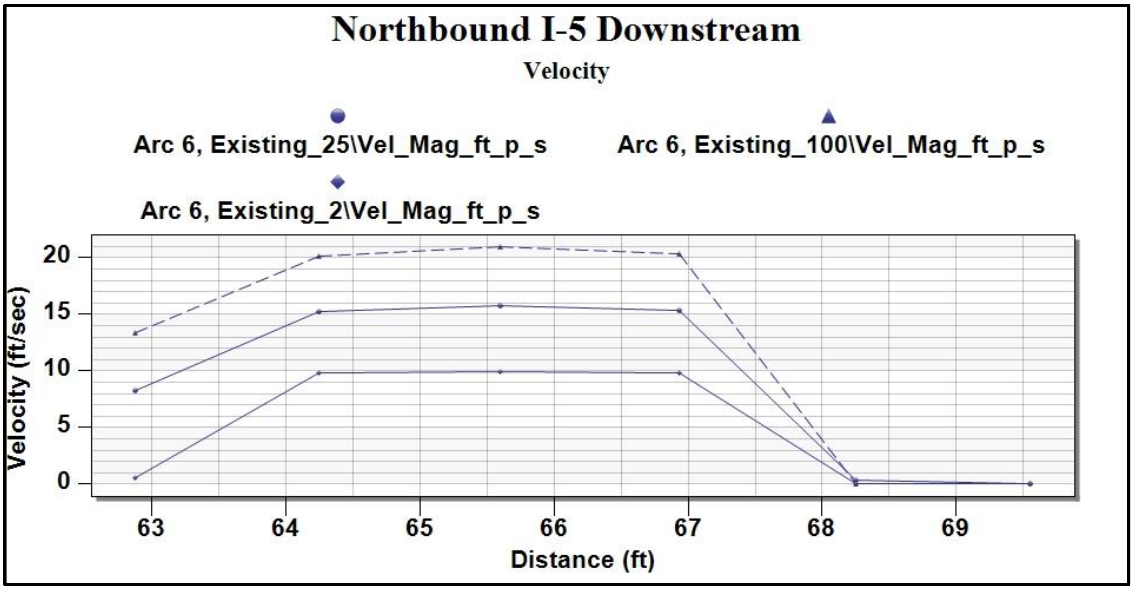


Figure A.2.5
Secret Creek at I-5 Northbound

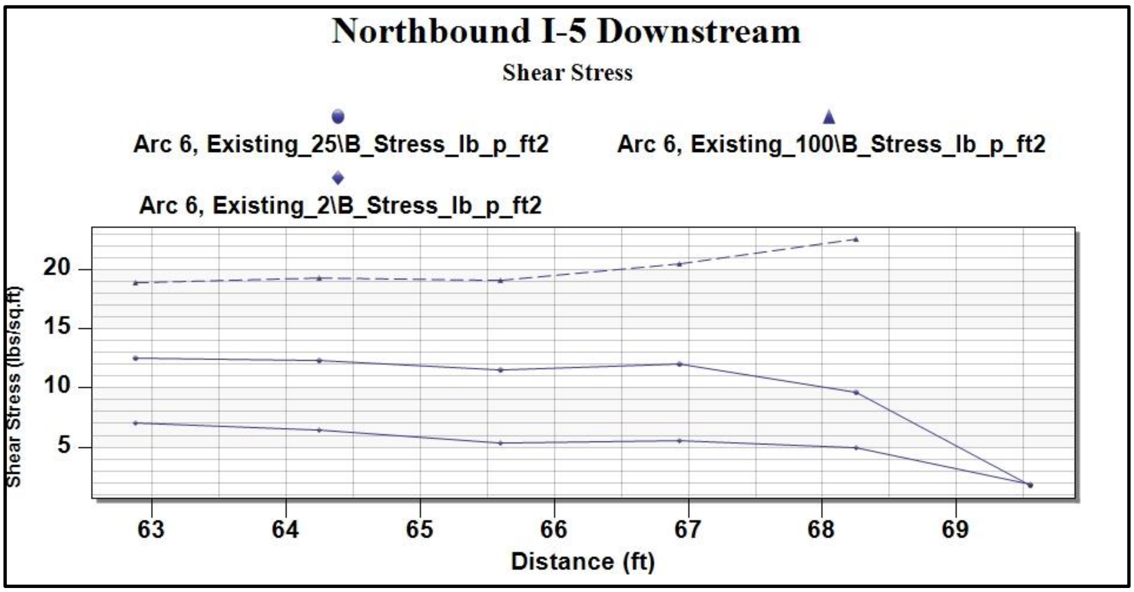
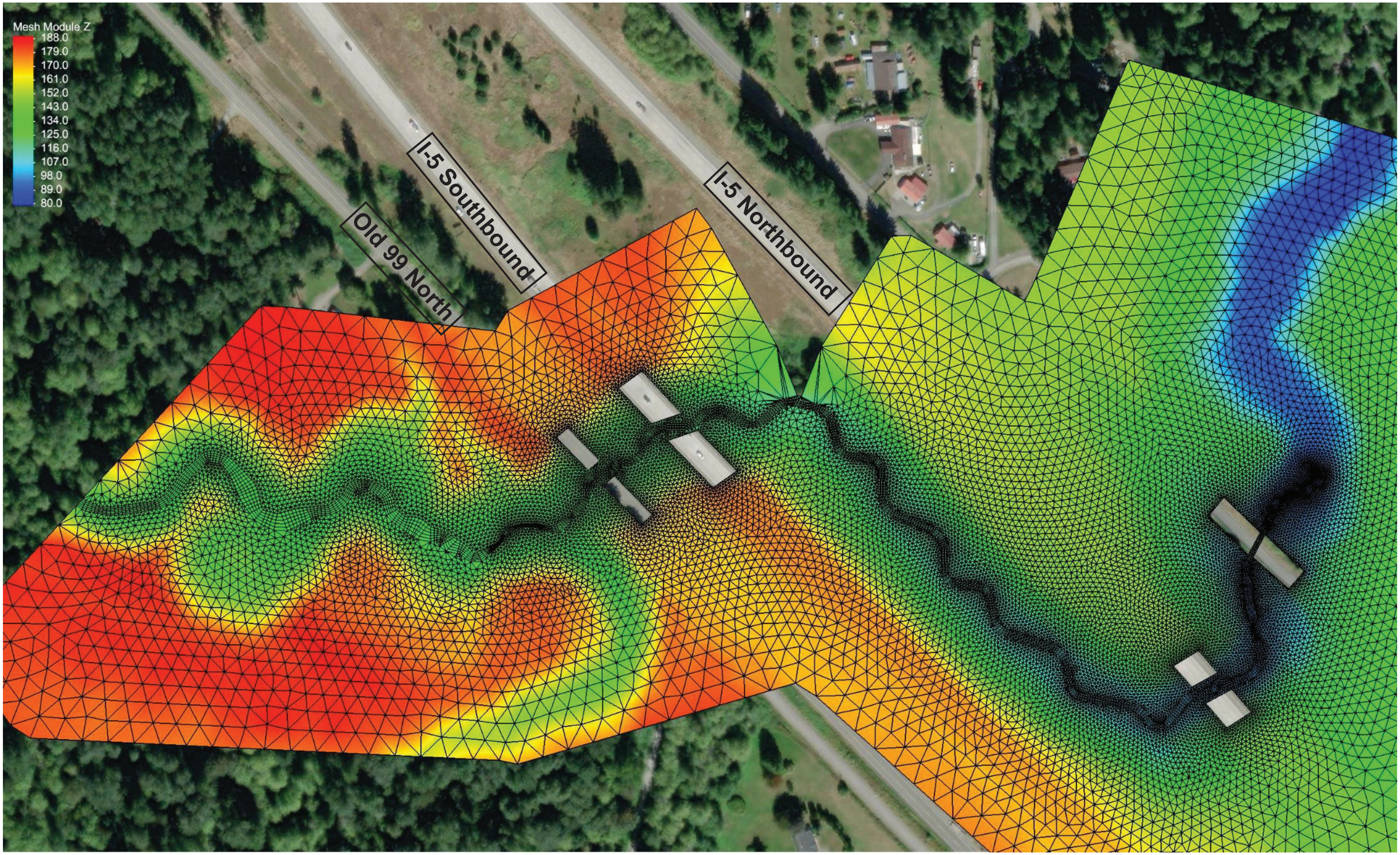


Figure A.2.6
Secret Creek at I-5 Northbound

Appendix D

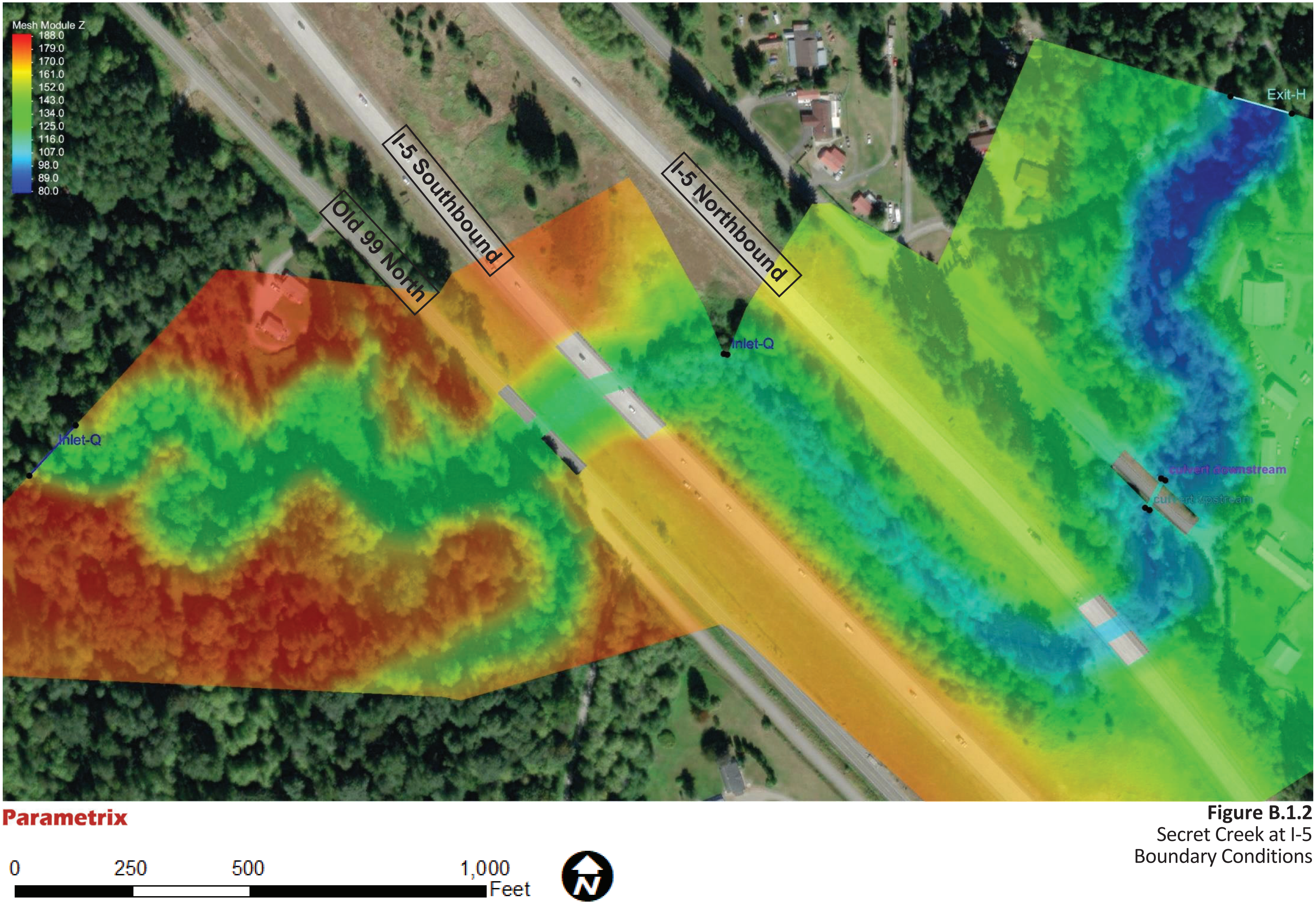
SRH-2D Proposed Conditions Model Results

This Page Intentionally Left Blank



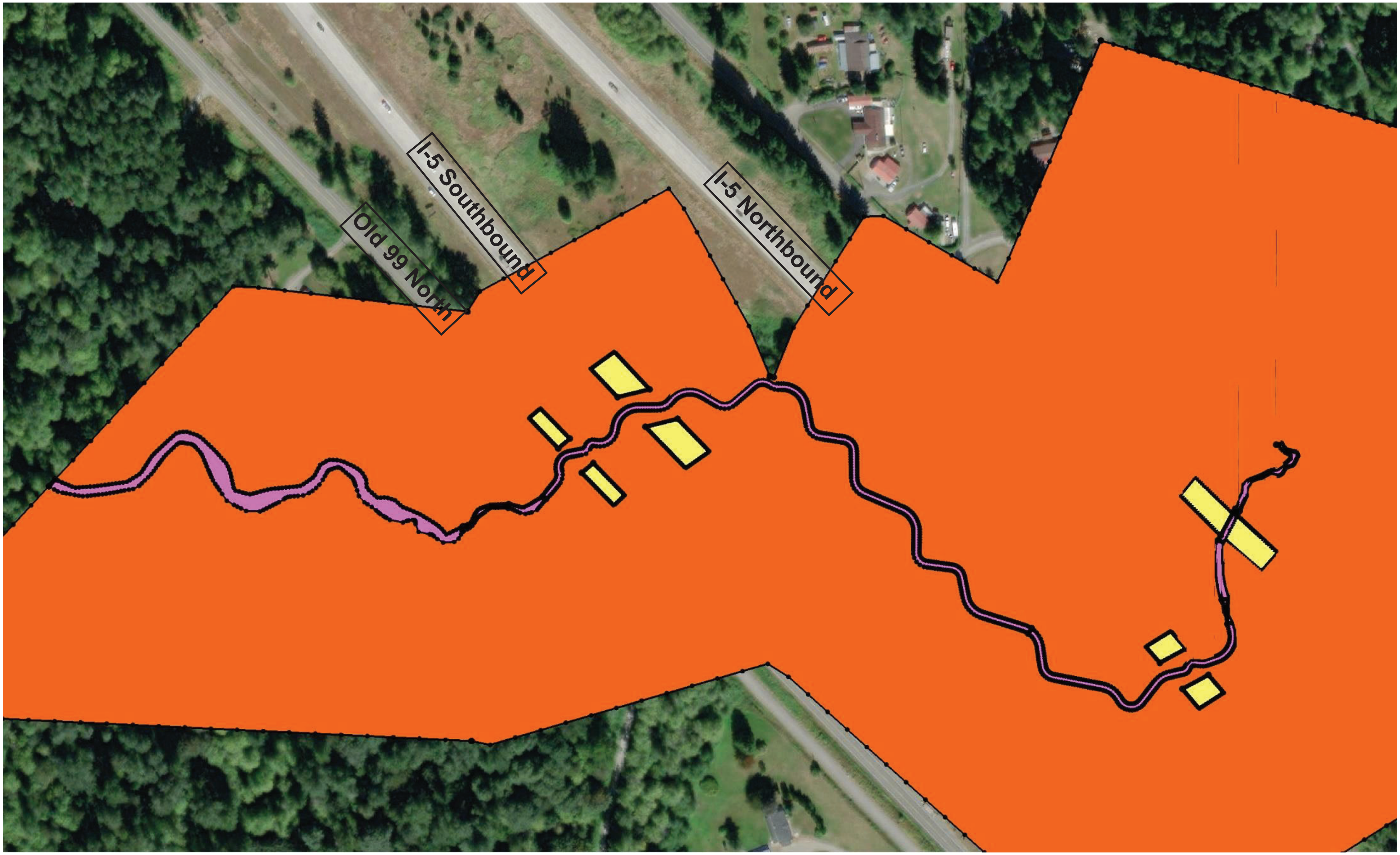
Parametrix

Figure B.1.1
Secret Creek at I-5
SRH2D Model Mesh



Parametrix

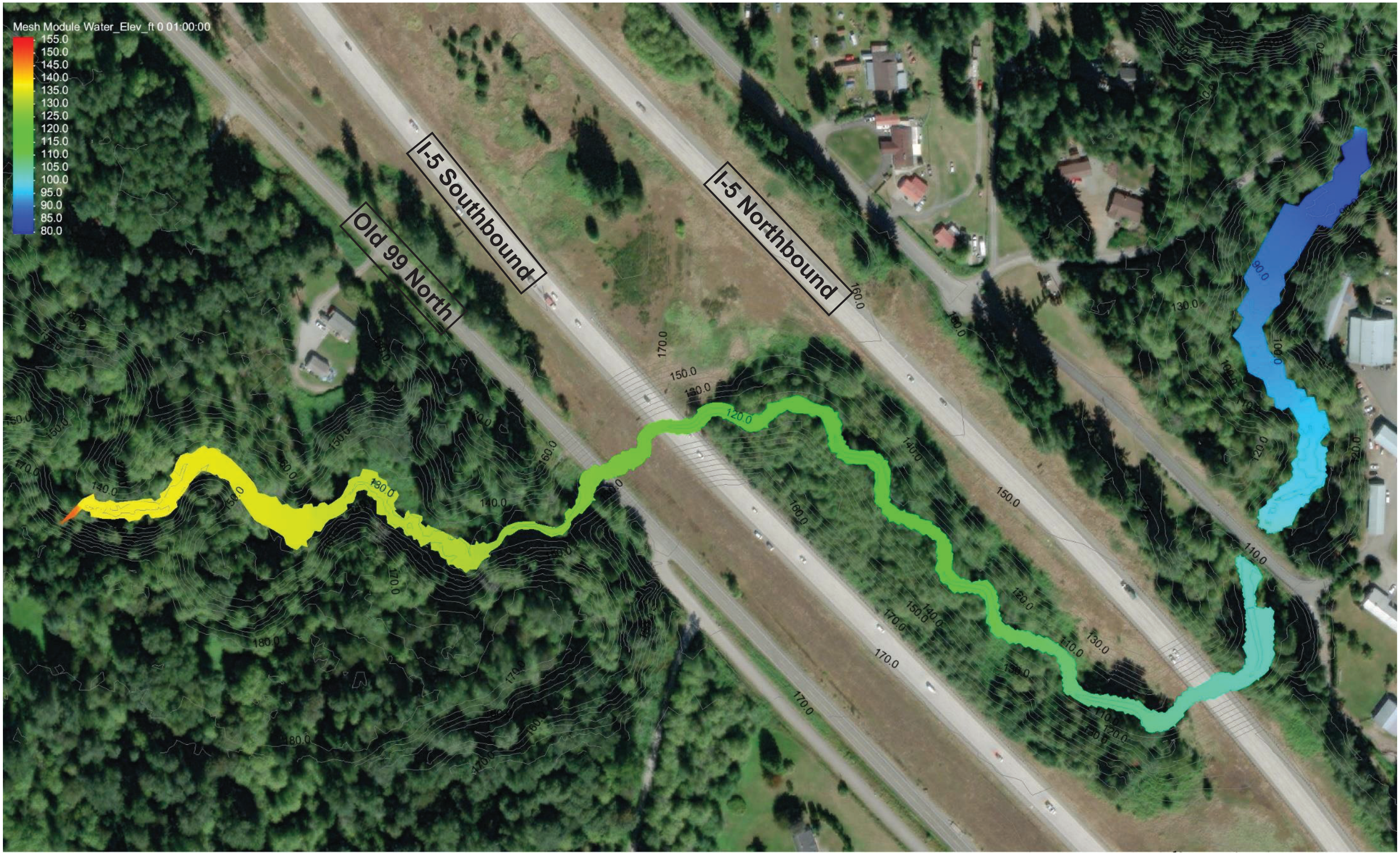
Figure B.1.2
Secret Creek at I-5
Boundary Conditions



Parametrix

0 250 500 1,000 Feet

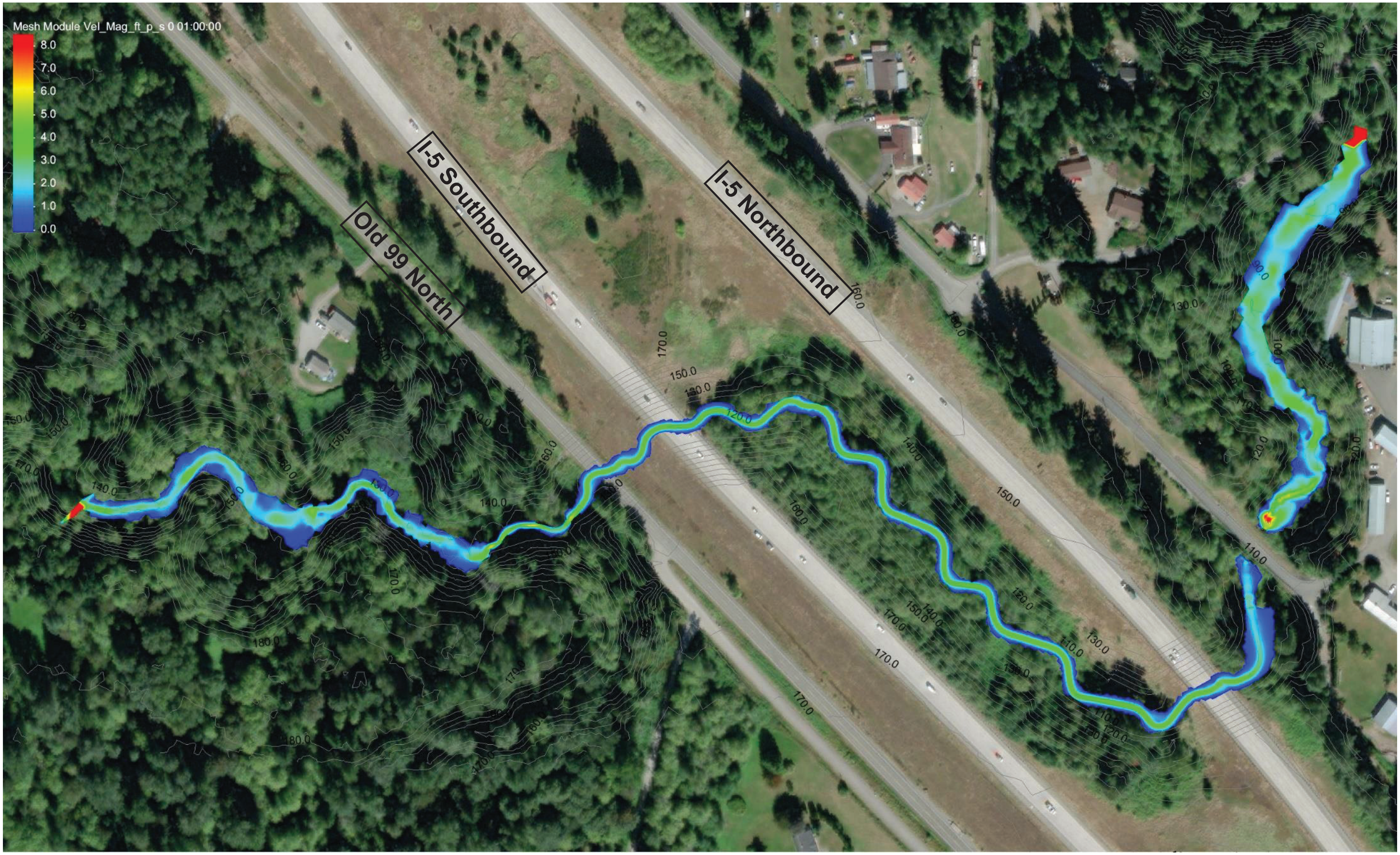
Figure B.1.3
Secret Creek at I-5
Model Roughness



Parametrix

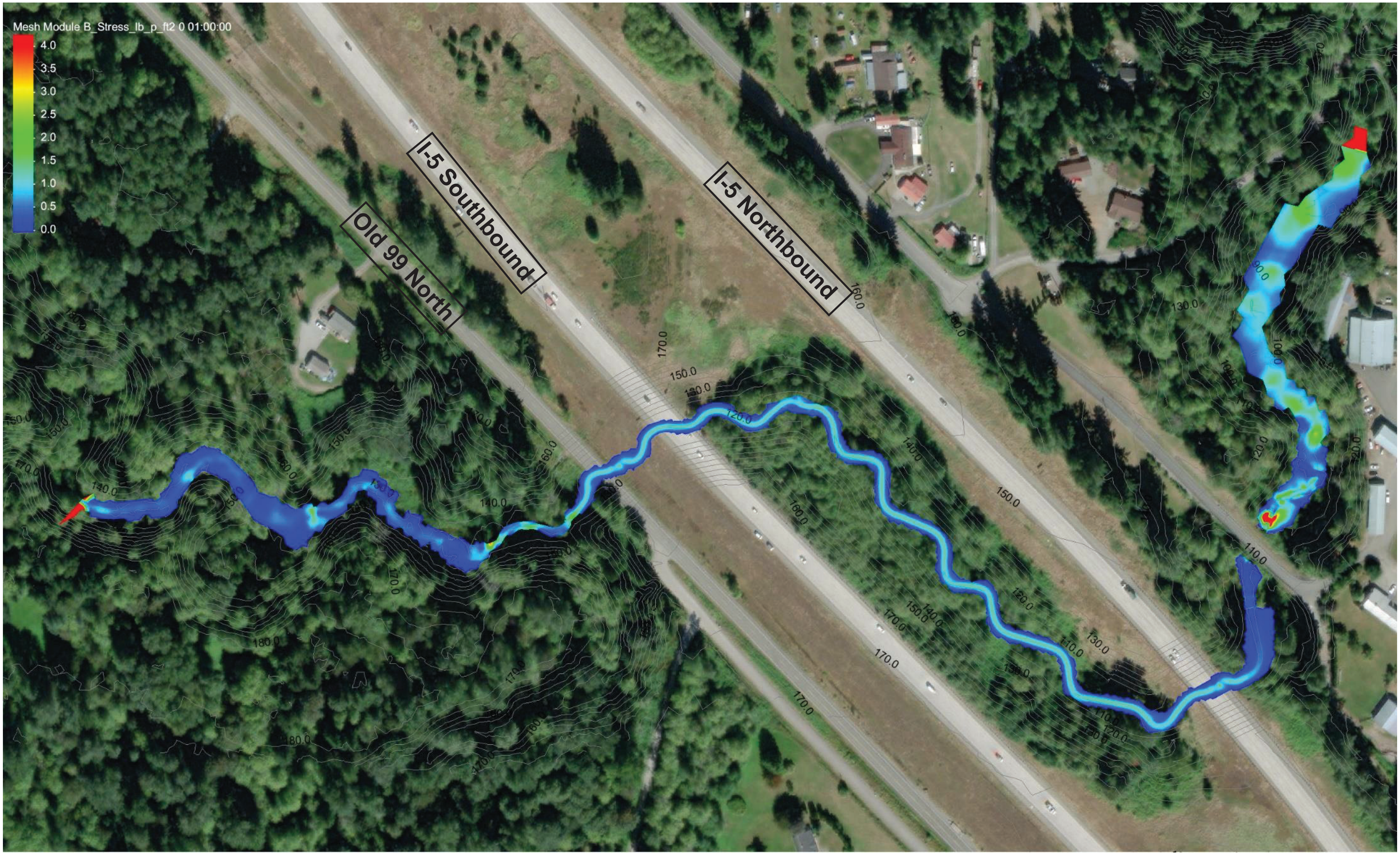
0 250 500 1,000 Feet

Figure B.1.4
Secret Creek at I-5
2-Year Water Surface Elevation



Parametrix

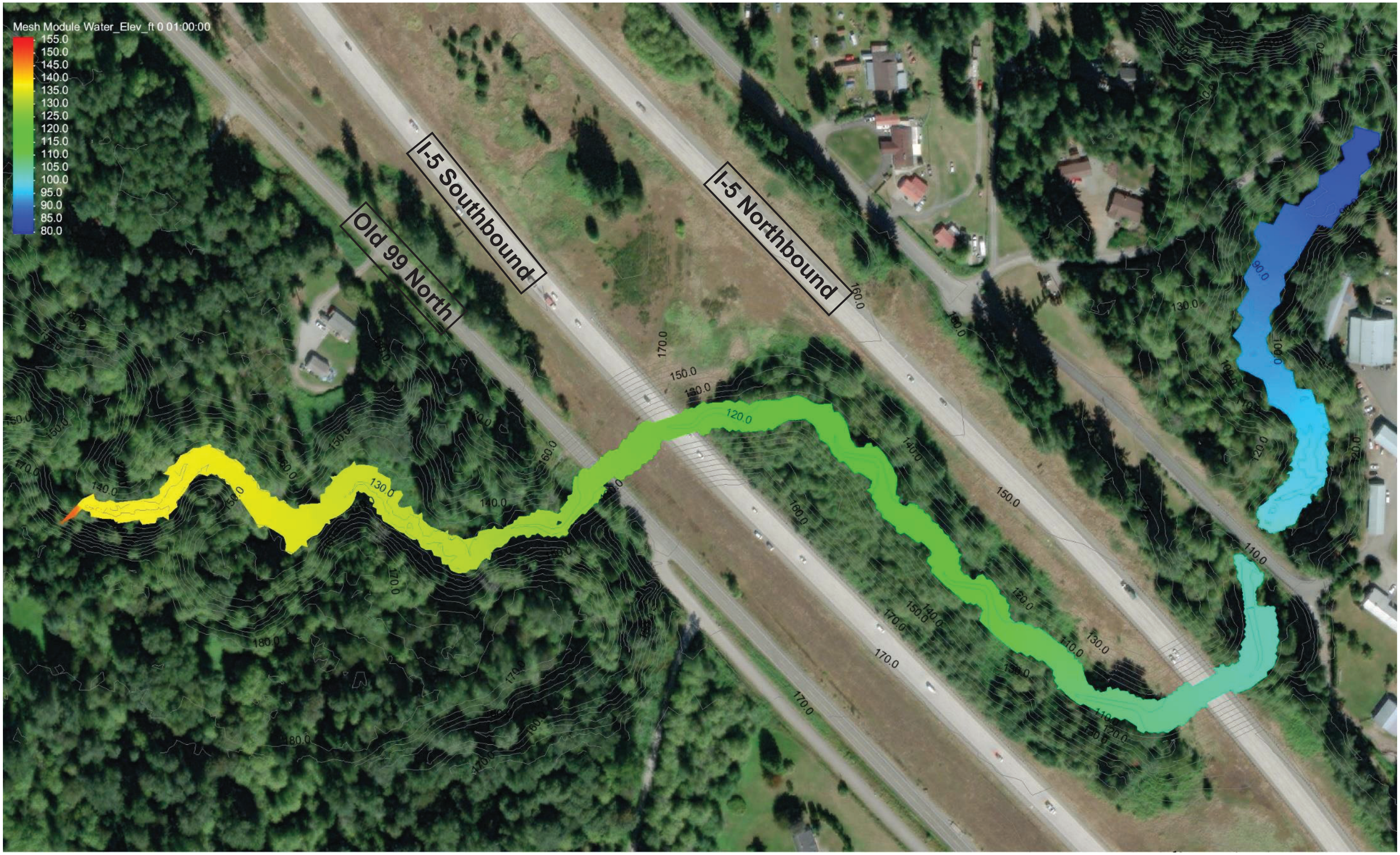
Figure B.1.5
Secret Creek at I-5
2-Year Velocity



Parametrix

0 250 500 1,000 Feet

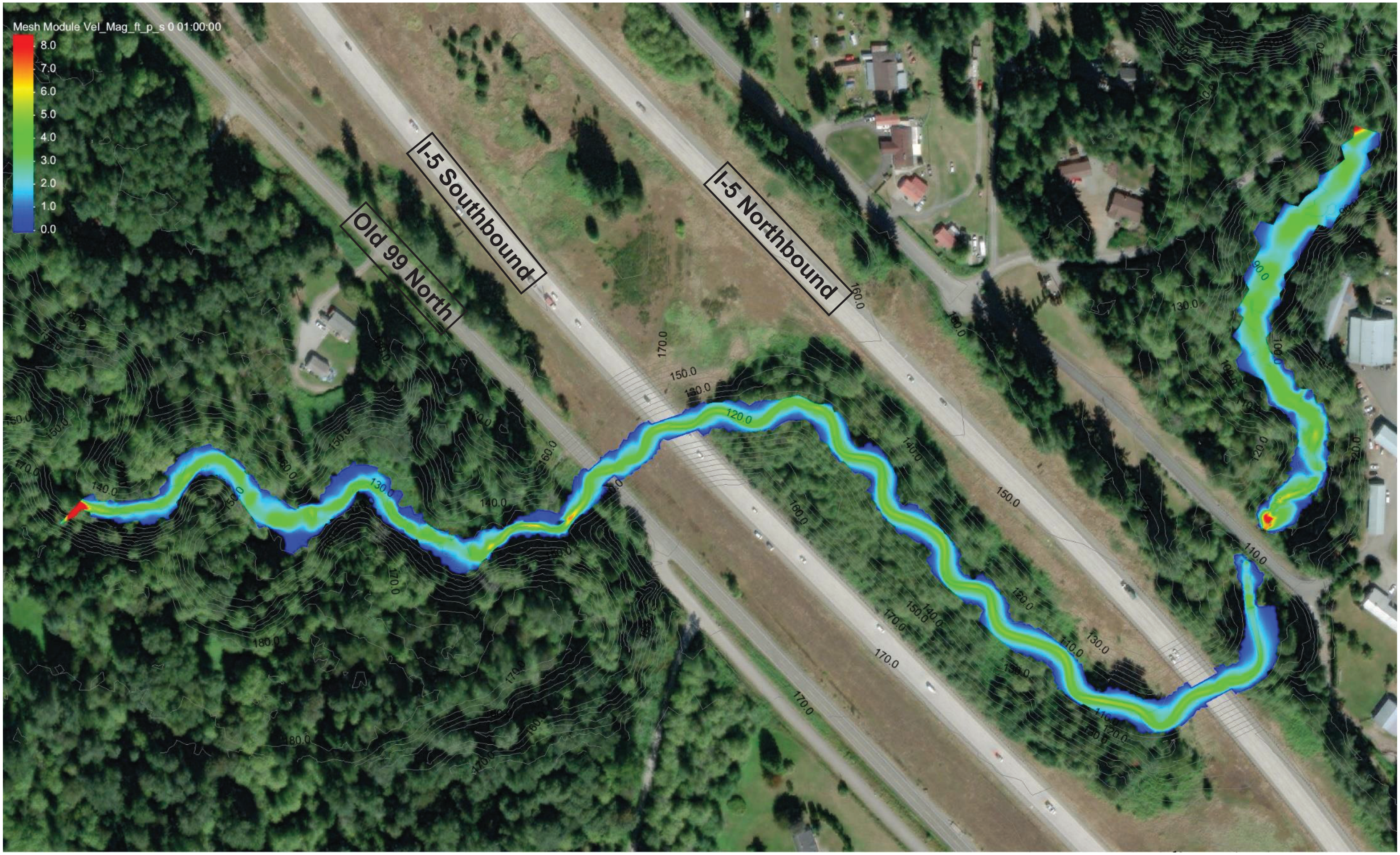
Figure B.1.6
Secret Creek at I-5
2-Year Shear Stress



Parametrix

0 250 500 1,000 Feet

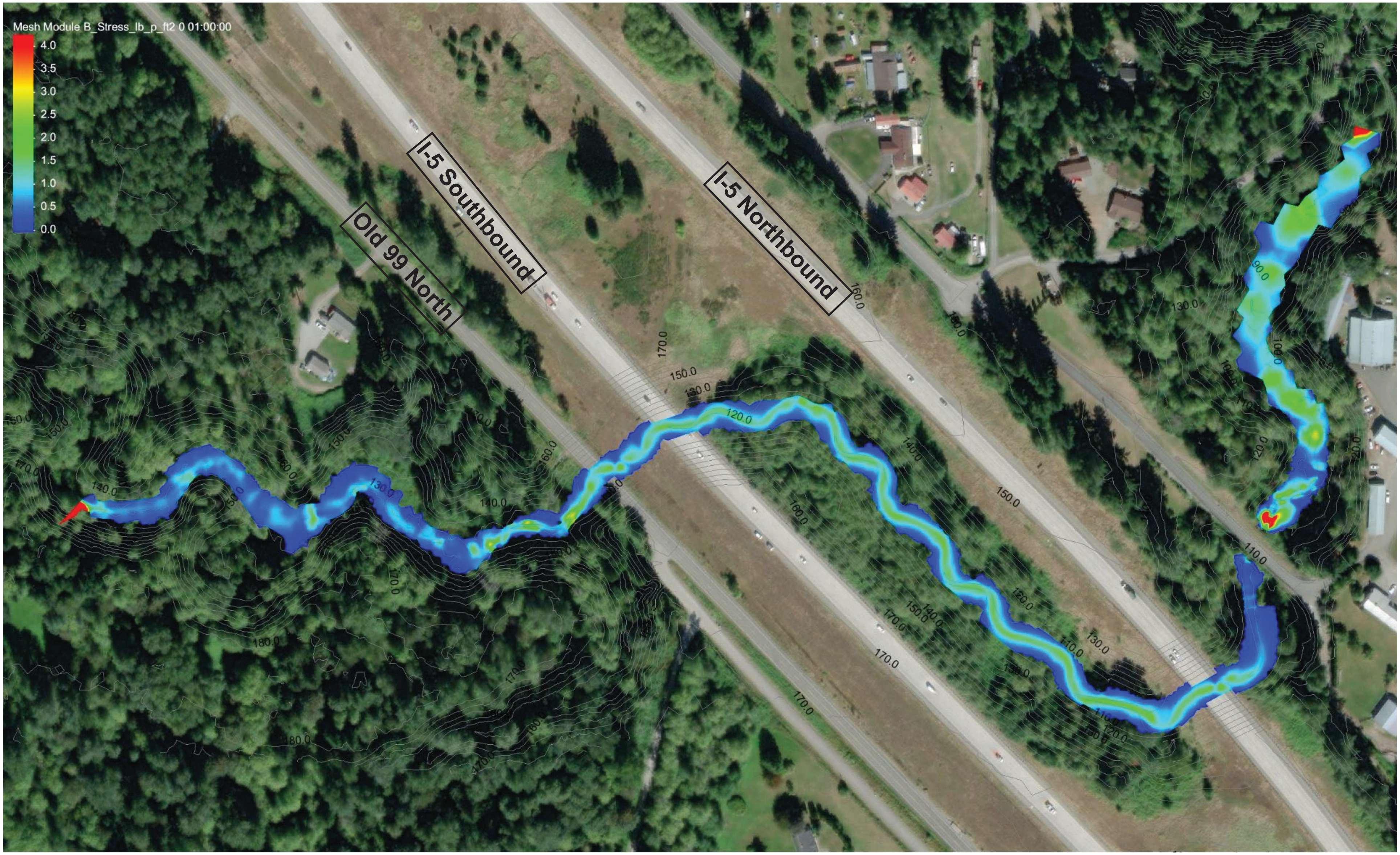
Figure B.1.7
Secret Creek at I-5
25-Year Water Surface Elevation



Parametrix

0 250 500 1,000 Feet

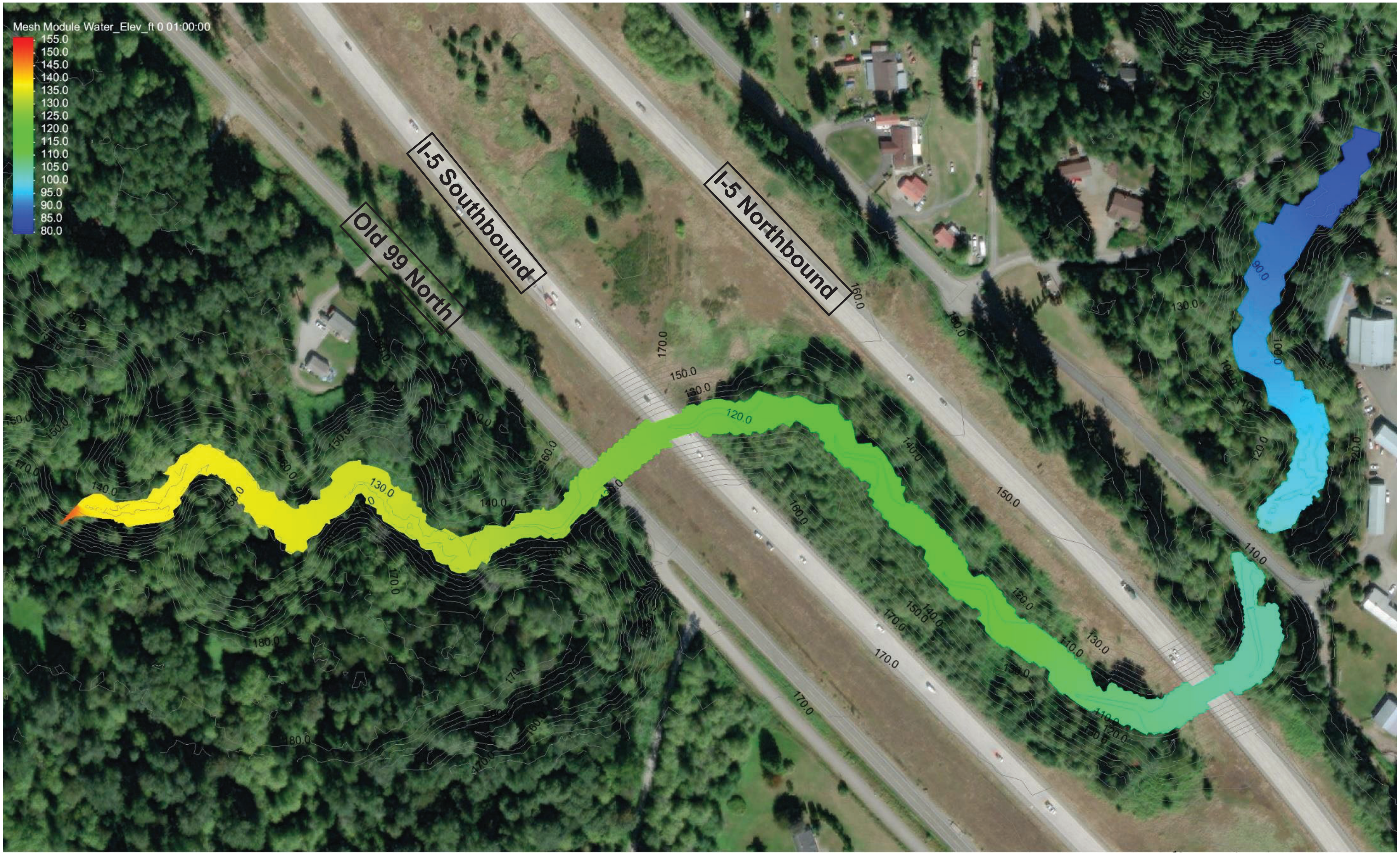
Figure B.1.8
Secret Creek at I-5
25-Year Velocity



Parametrix

0 250 500 1,000 Feet

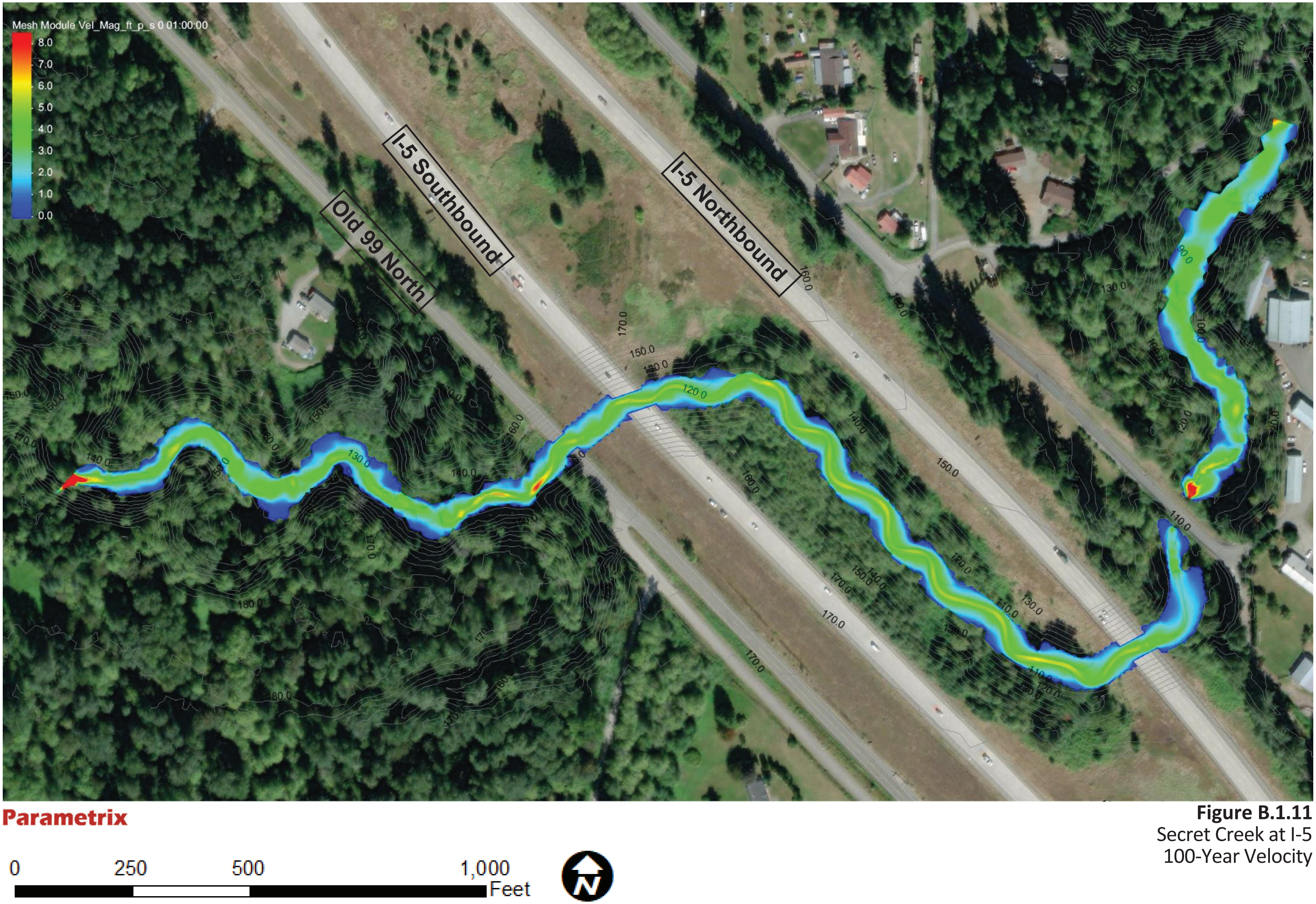
Figure B.1.9
Secret Creek at I-5
25-Year Shear Stress



Parametrix

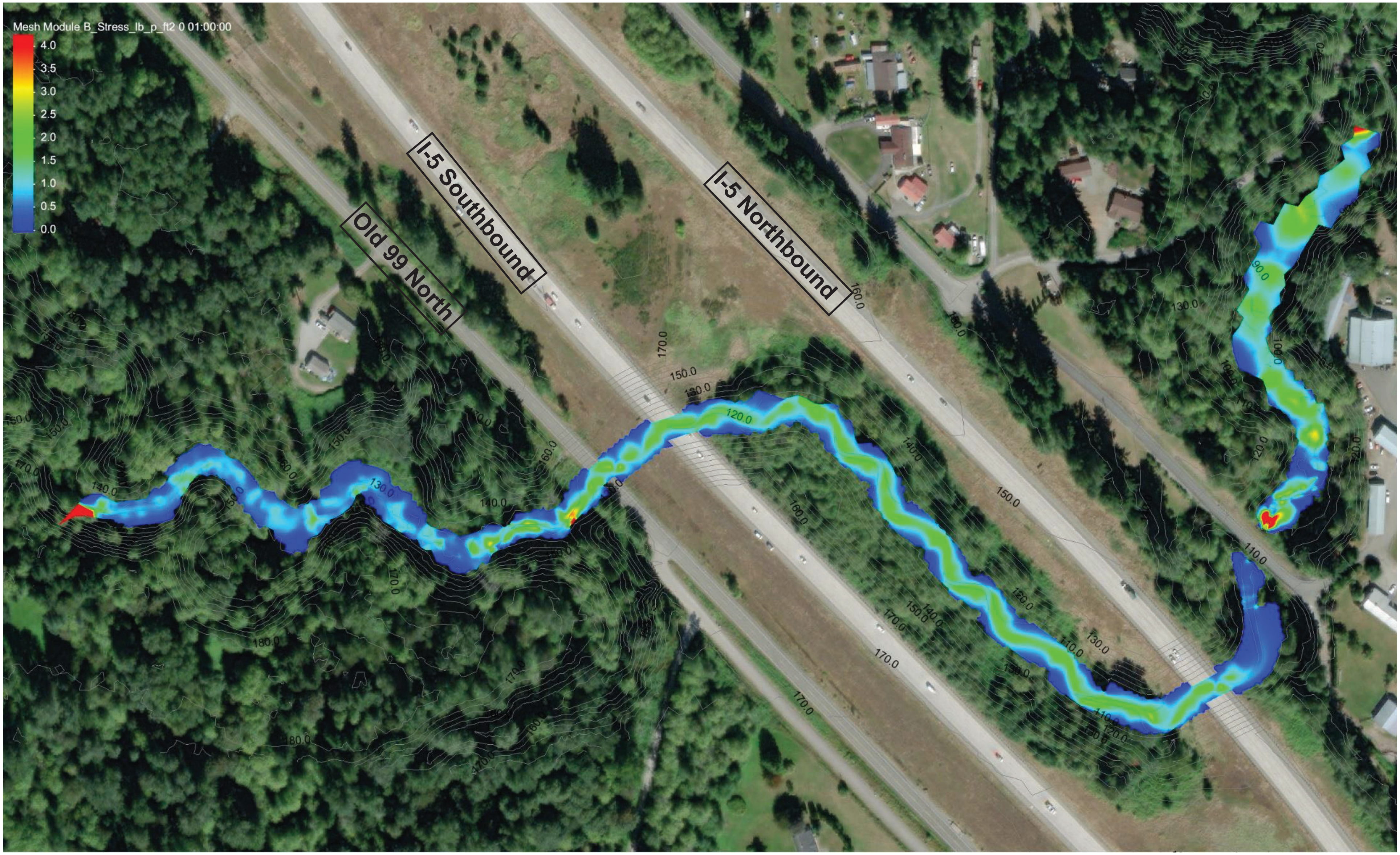
0 250 500 1,000 Feet

Figure B.1.10
Secret Creek at I-5
100-Year Water Surface Elevation



Parametrix

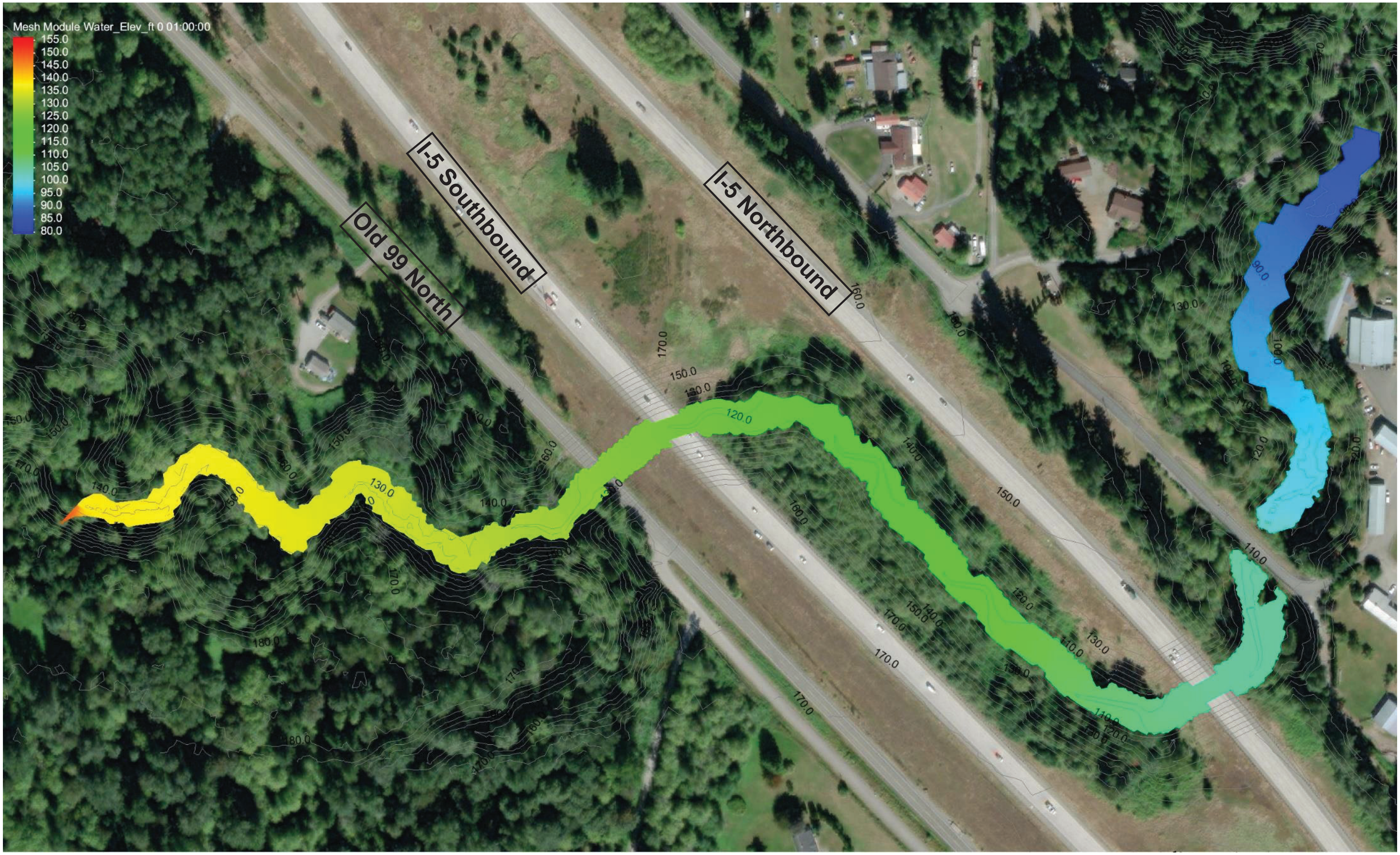
Figure B.1.11
Secret Creek at I-5
100-Year Velocity



Parametrix

0 250 500 1,000 Feet

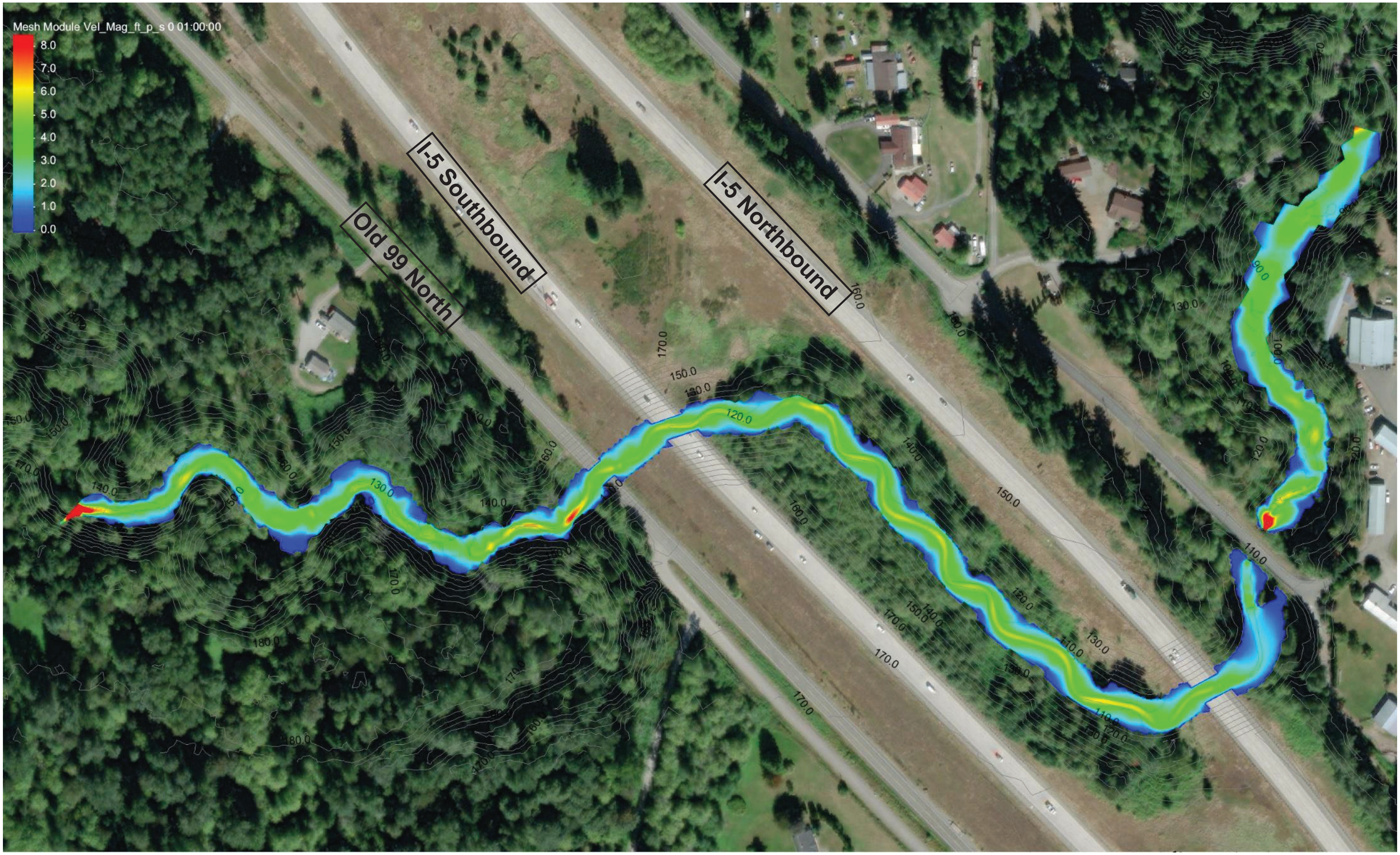
Figure B.1.12
Secret Creek at I-5
100-Year Shear Stress



Parametrix

0 250 500 1,000 Feet

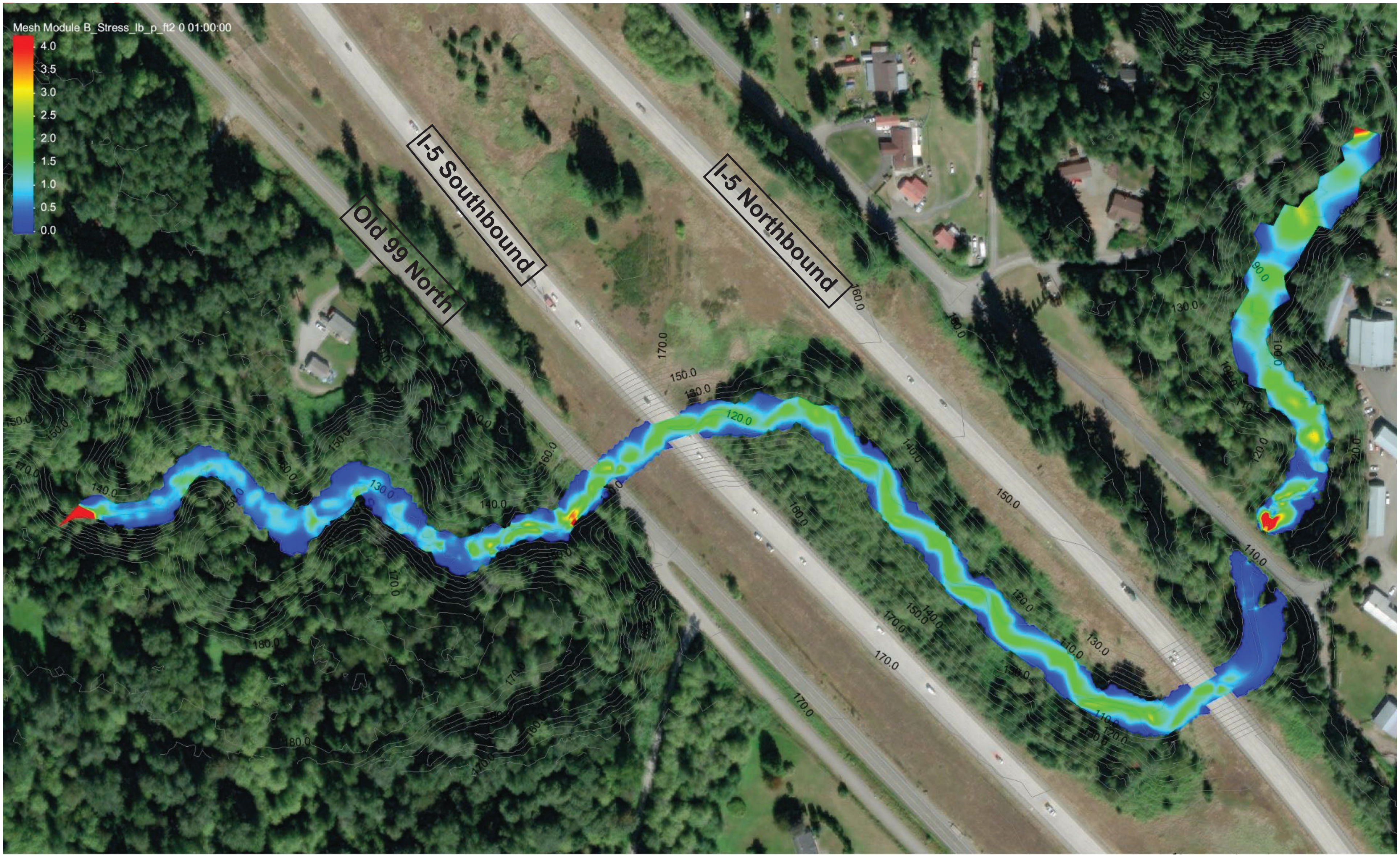
Figure B.1.13
Secret Creek at I-5
500-Year Water Surface Elevation



Parametrix

0 250 500 1,000 Feet

Figure B.1.14
Secret Creek at I-5
500-Year Velocity



Parametrix

0 250 500 1,000 Feet

Figure B.1.15
Secret Creek at I-5
500-Year Shear Stress

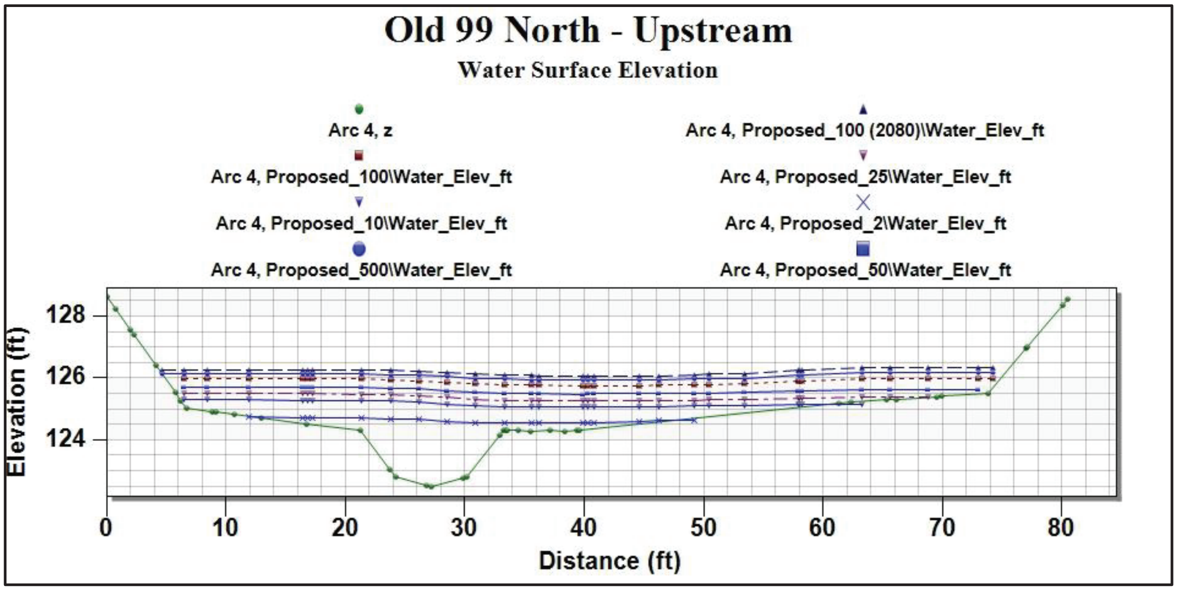


Figure B.2.1
Secret Creek at I-5

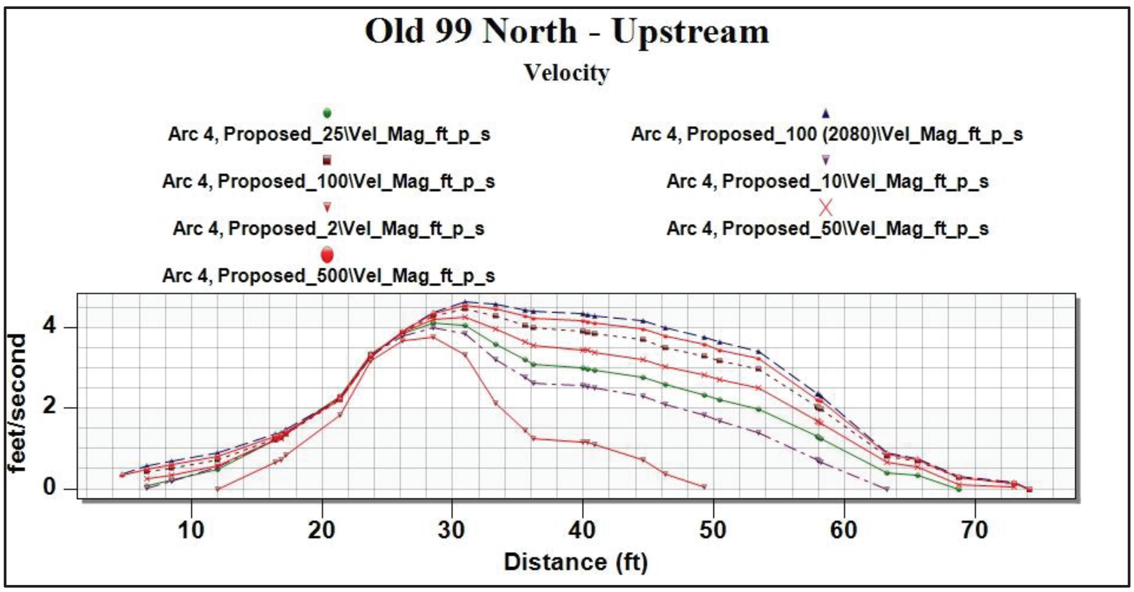


Figure B.2.2
Secret Creek at I-5

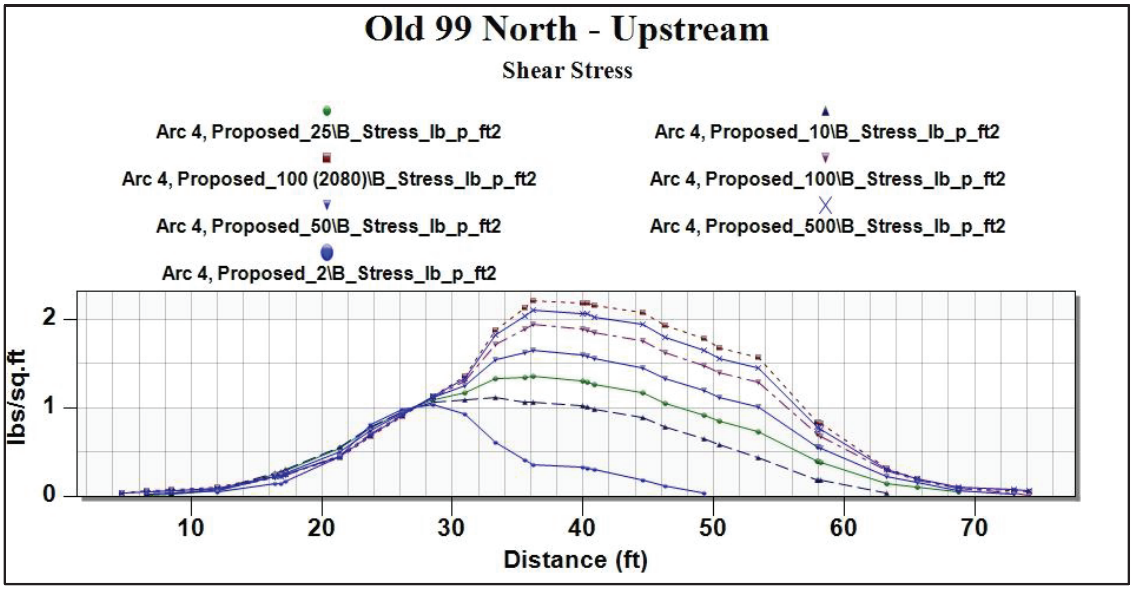


Figure B.2.3
Secret Creek at I-5

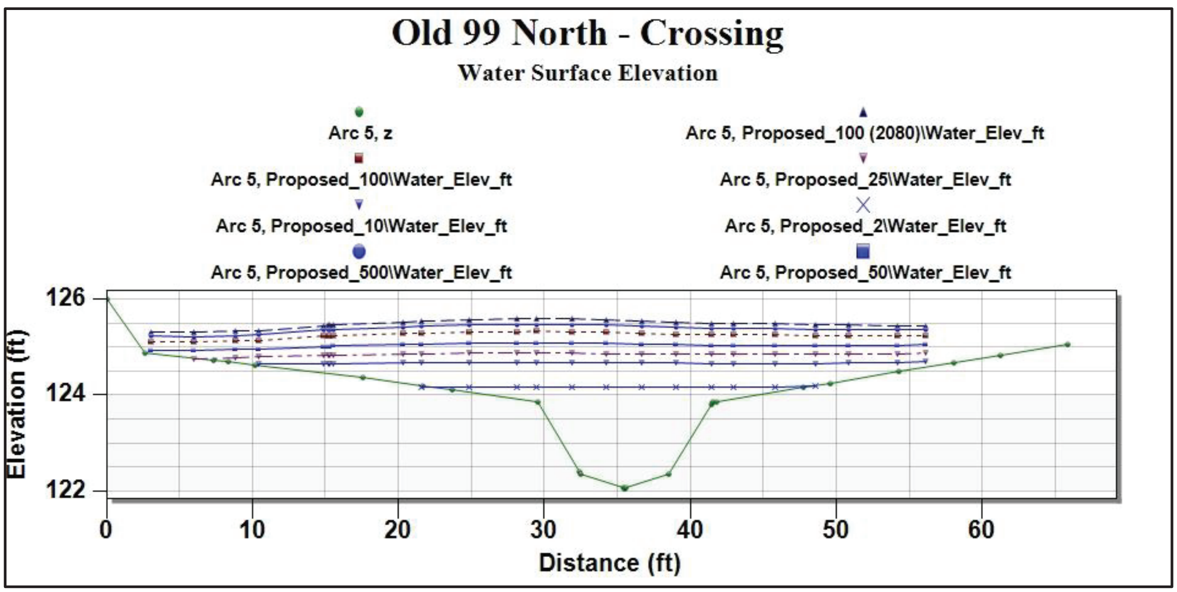


Figure B.2.4
Secret Creek at I-5

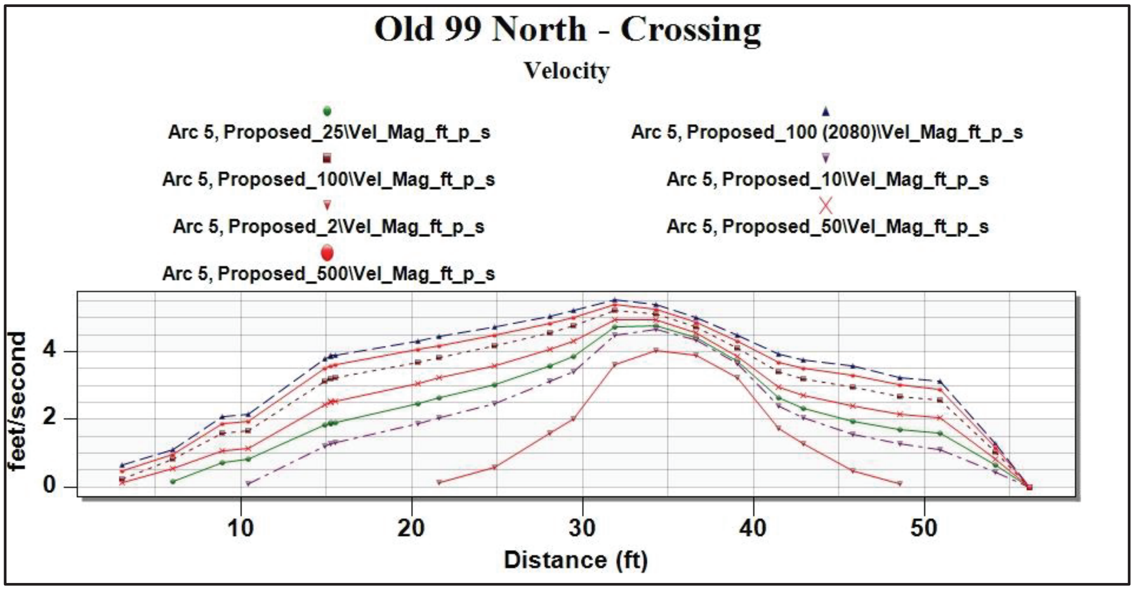


Figure B.2.5
Secret Creek at I-5

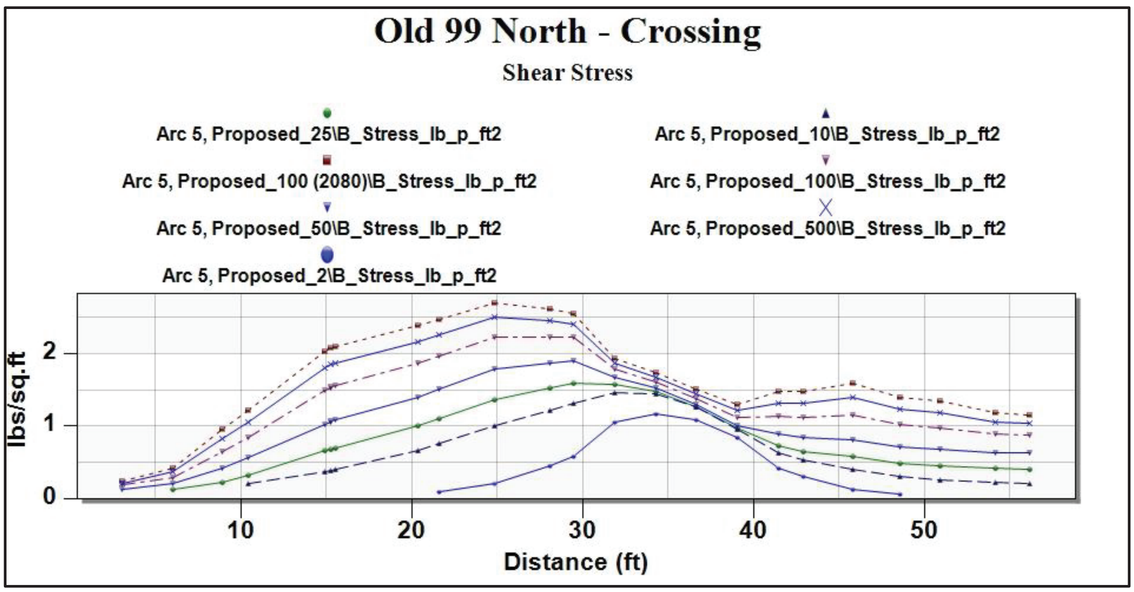


Figure B.2.6
Secret Creek at I-5

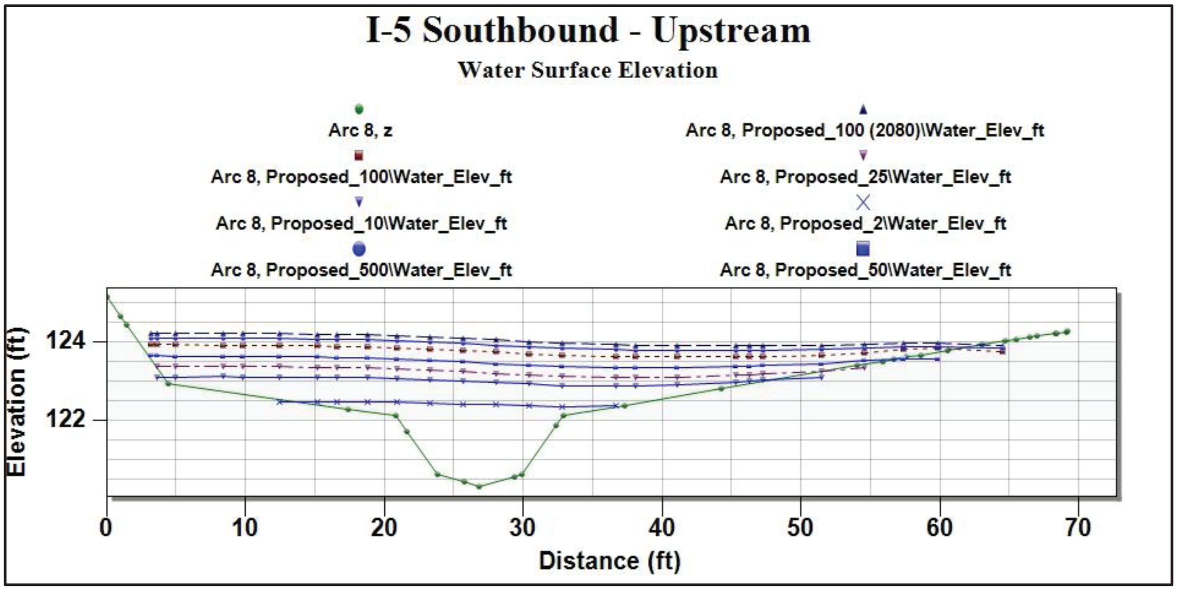


Figure B.2.7
Secret Creek at I-5

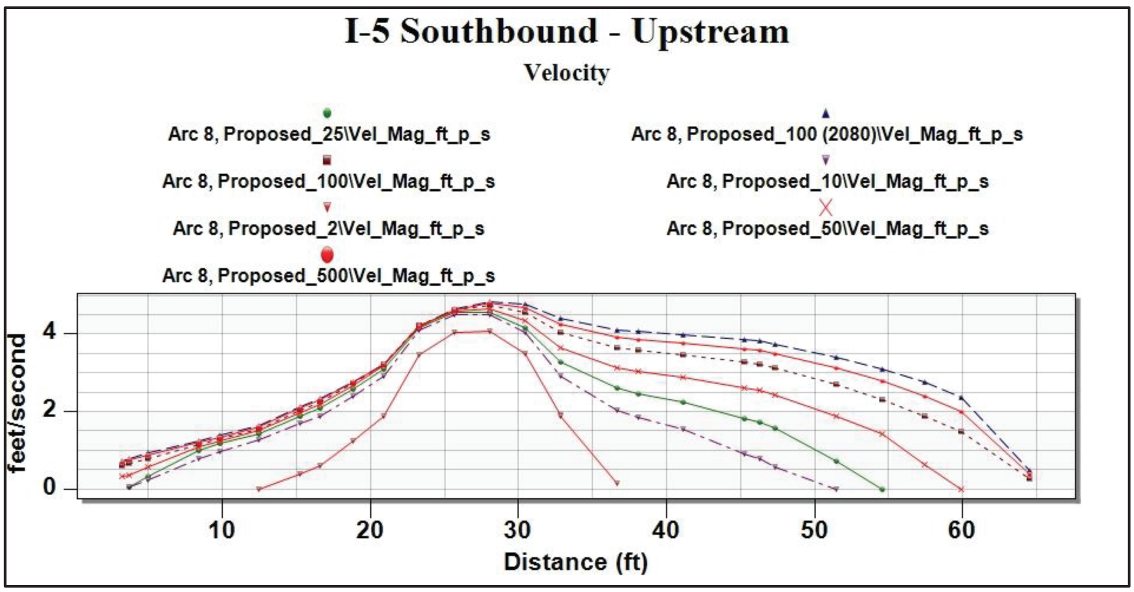


Figure B.2.8
Secret Creek at I-5

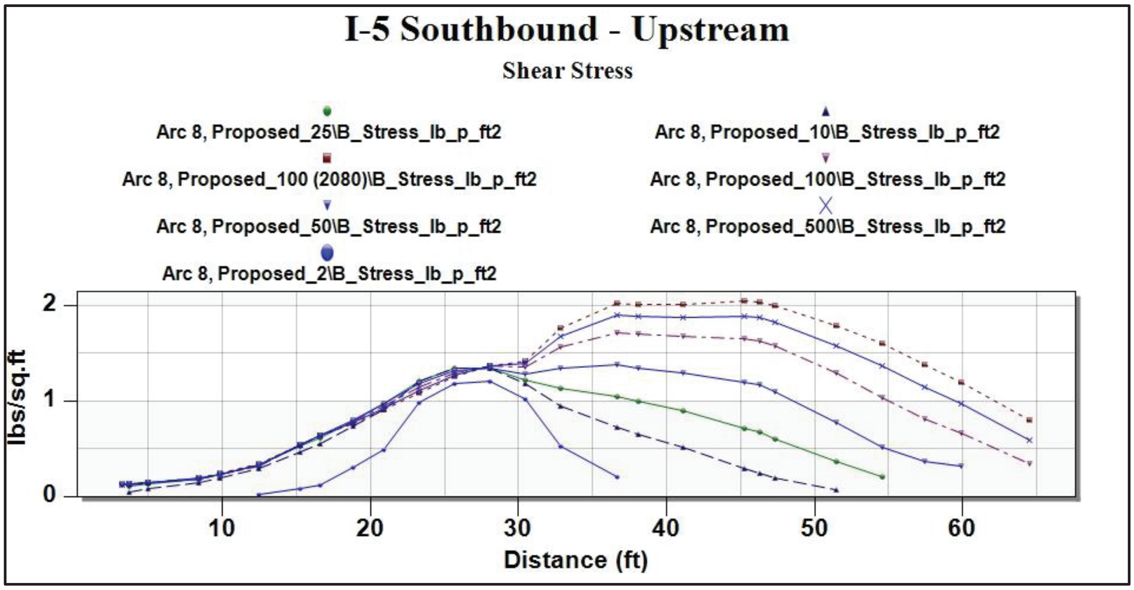


Figure B.2.9
Secret Creek at I-5

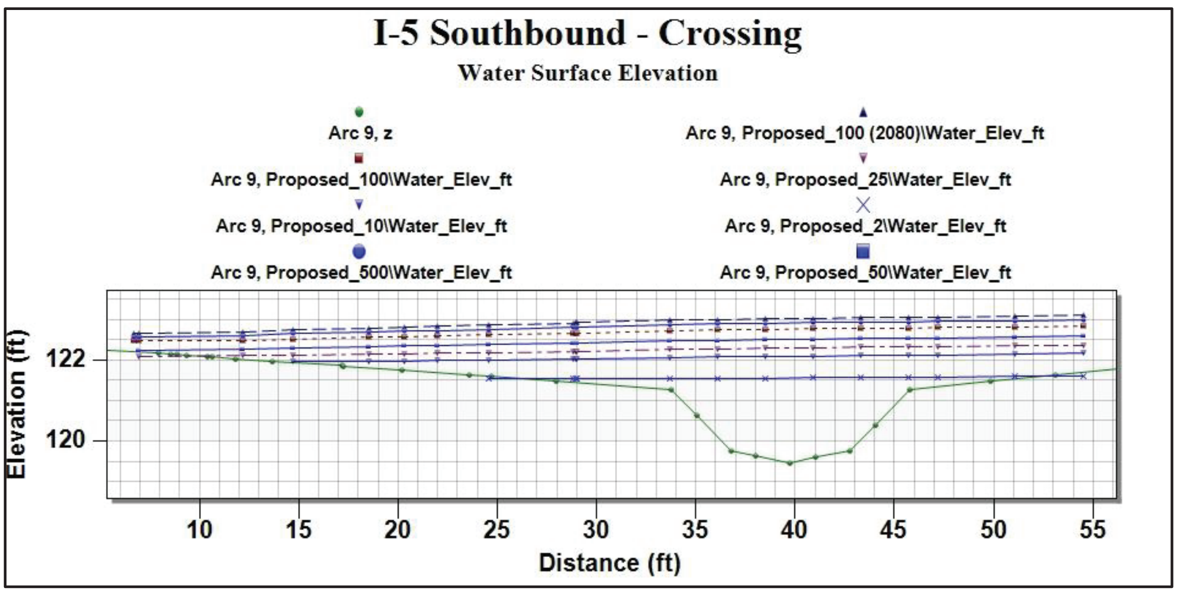


Figure B.2.10
Secret Creek at I-5

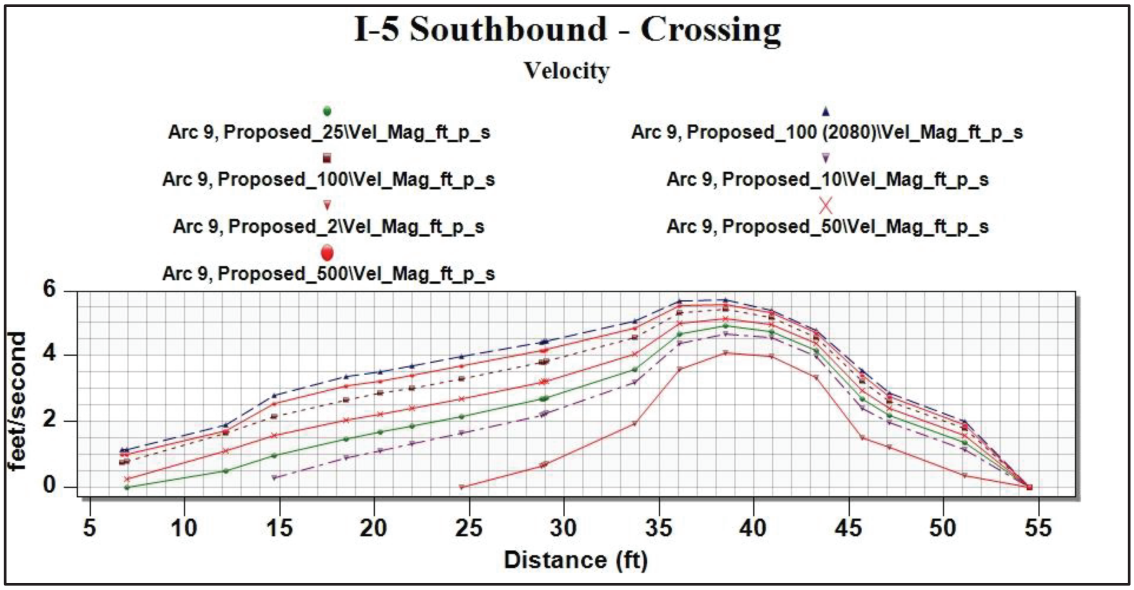


Figure B.2.11
Secret Creek at I-5

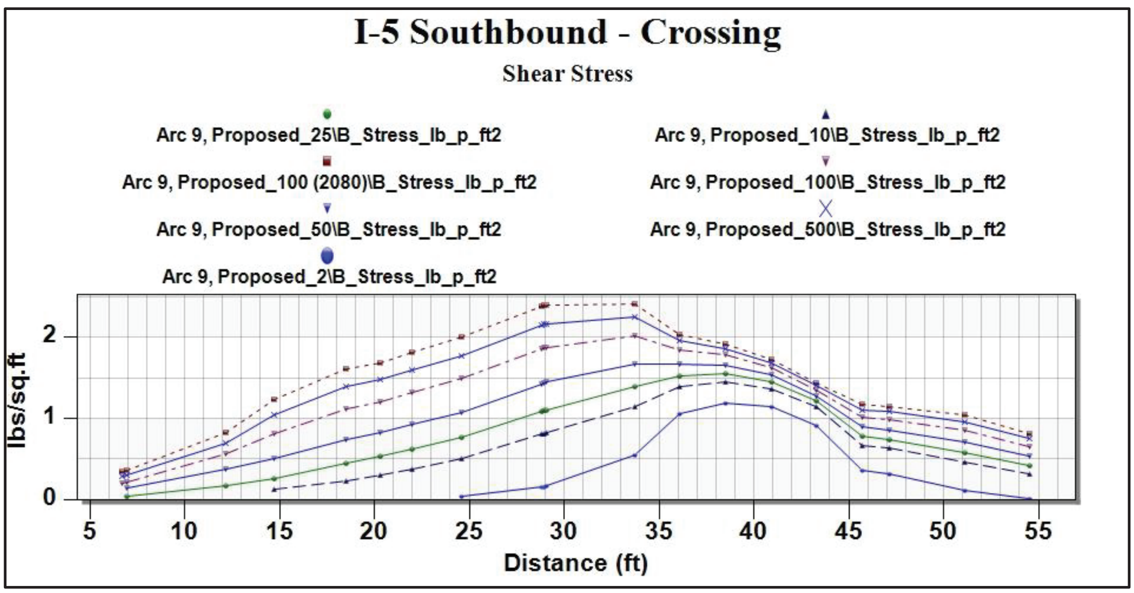


Figure B.2.12
Secret Creek at I-5

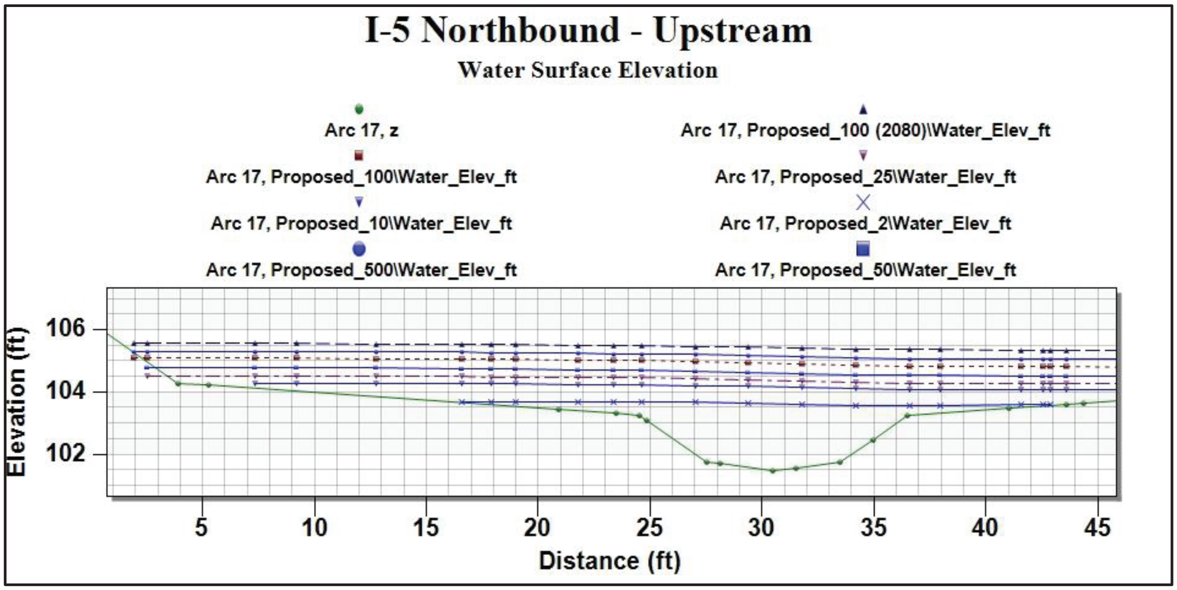


Figure B.2.13
Secret Creek at I-5

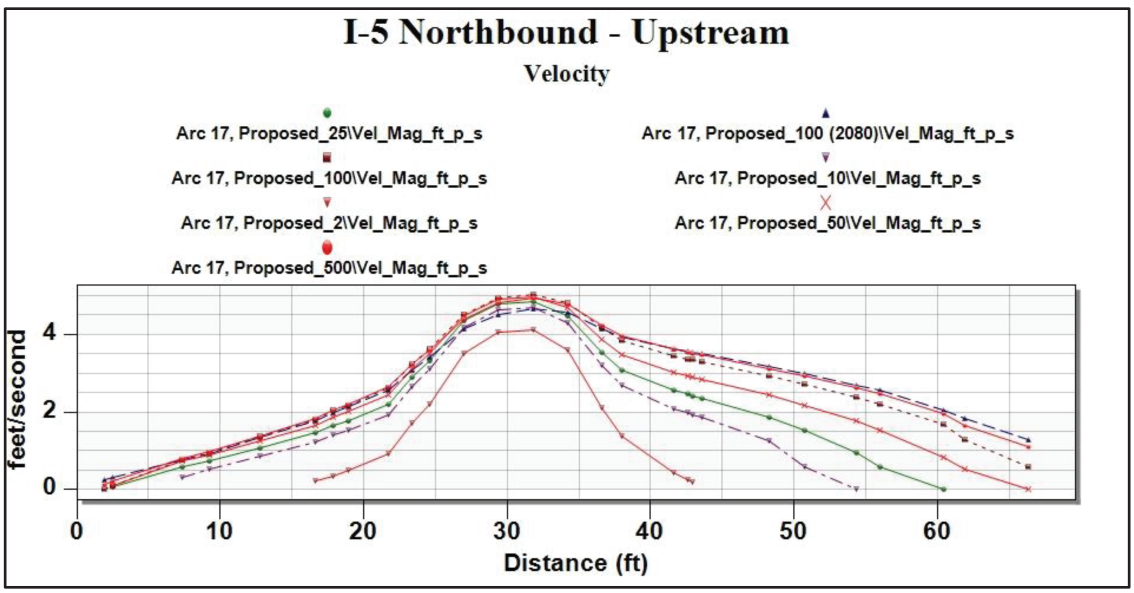


Figure B.2.14
Secret Creek at I-5

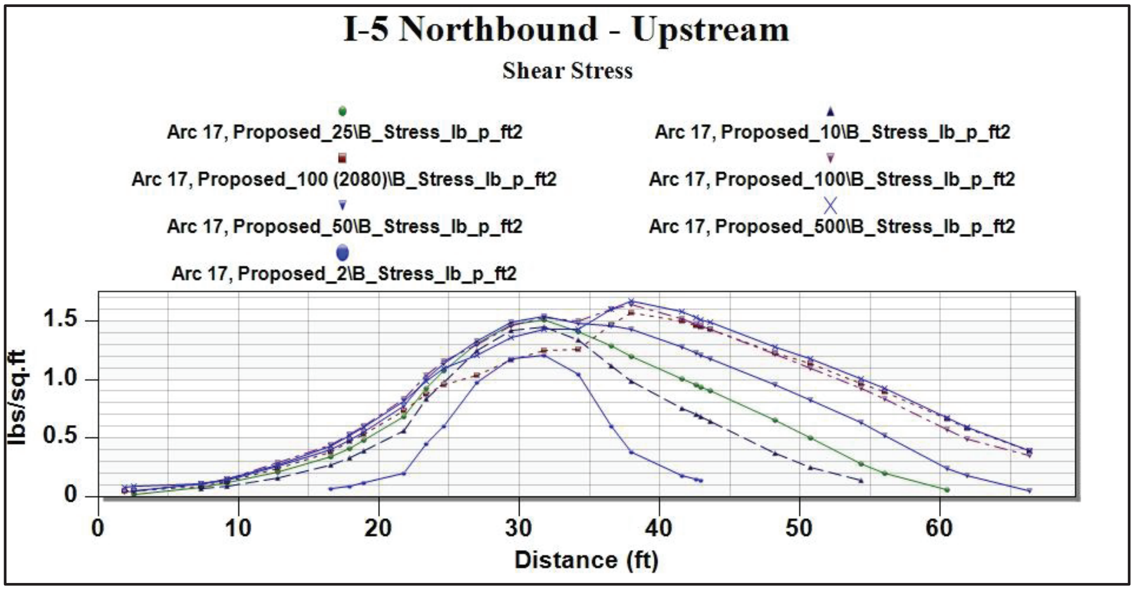


Figure B.2.15
Secret Creek at I-5

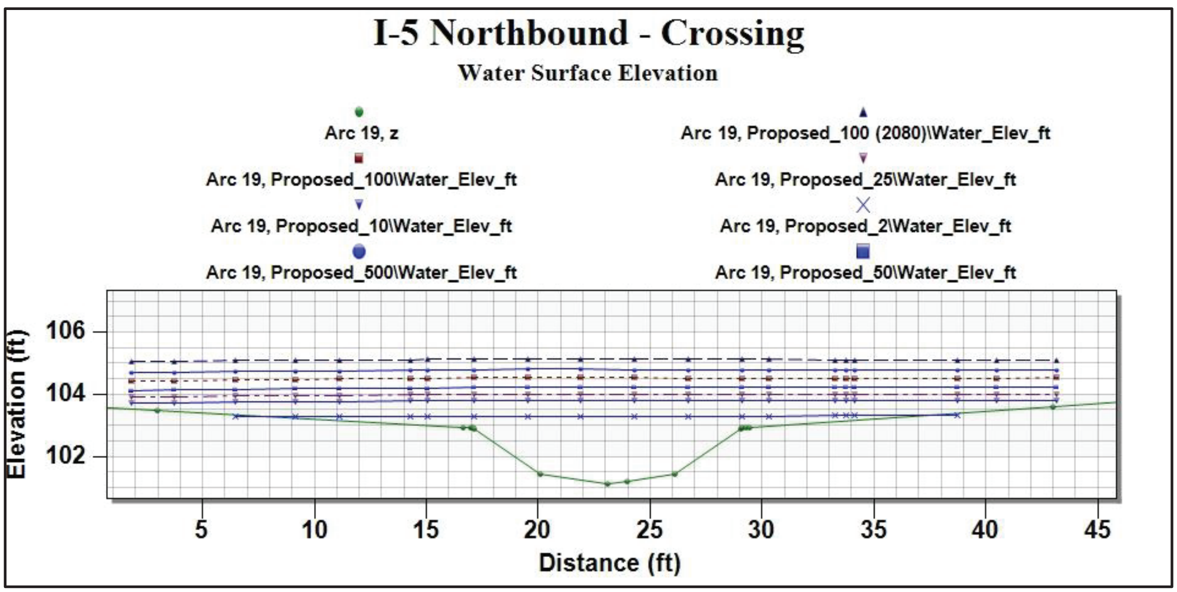


Figure B.2.16
Secret Creek at I-5

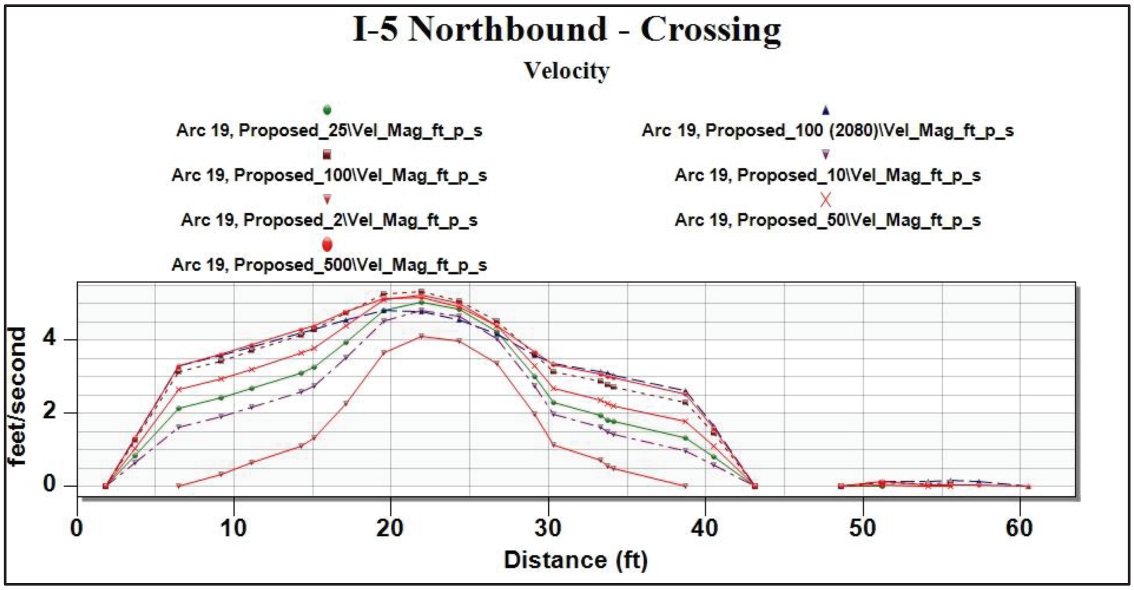


Figure B.2.17
Secret Creek at I-5

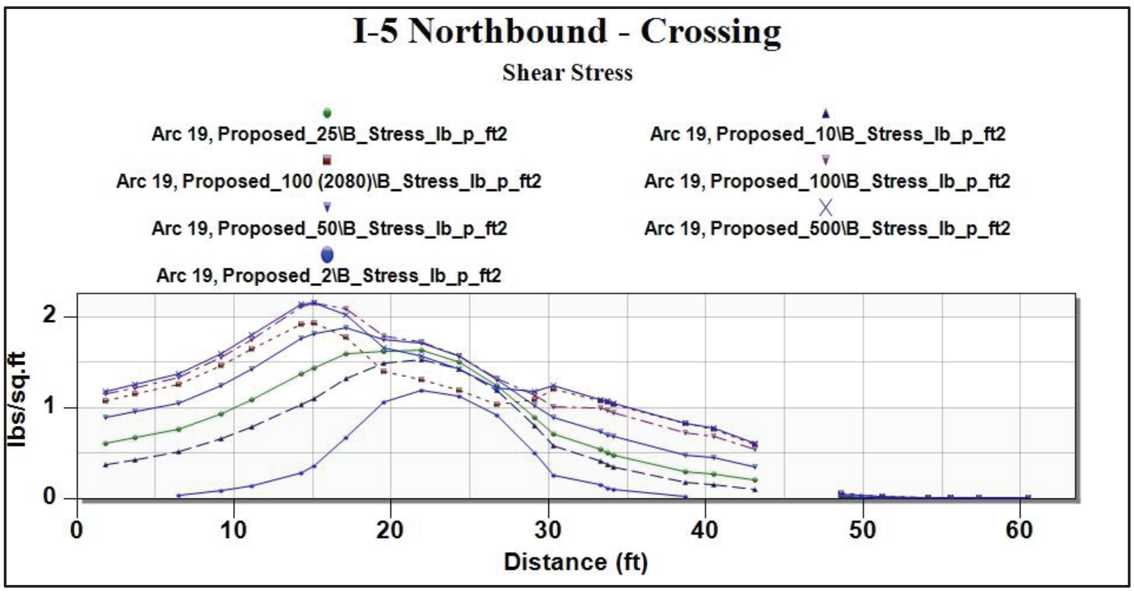
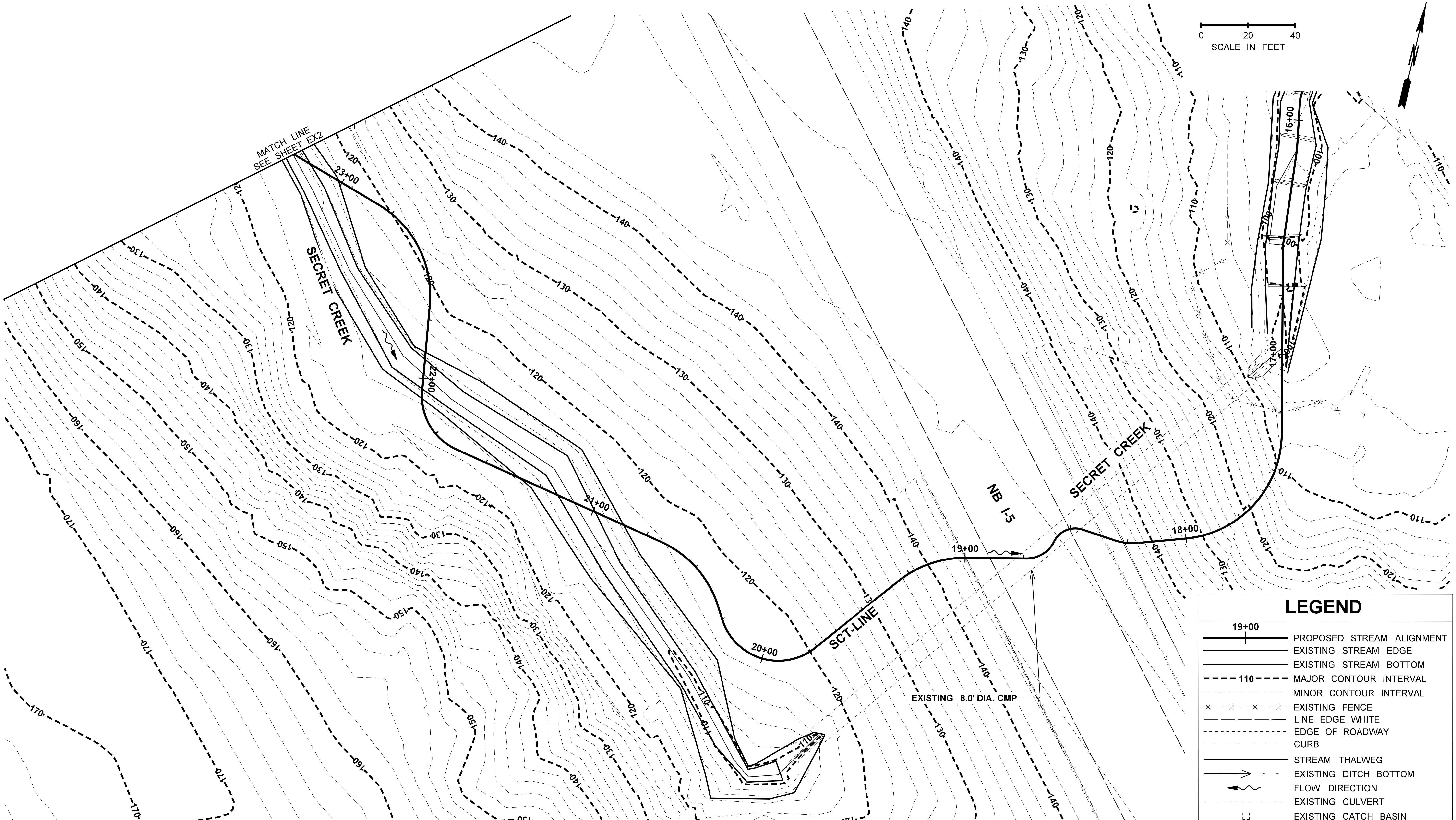


Figure B.2.18
Secret Creek at I-5

Appendix E

Preliminary Stream Plan, Profile, Details Sheets

This Page Intentionally Left Blank



PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_EX01.dgn			
TIME	12:47:04 PM			
DATE	7/30/2021			
PLOTTED BY	crosisus			
DESIGNED BY				
ENTERED BY	S. CROSIER			
CHECKED BY				
PROJ. ENGR.				
REGIONAL ADM.		REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX | DATE

PRELIMINARY

P.E. STAMP BOX | DATE

Washington State Department of Transportation

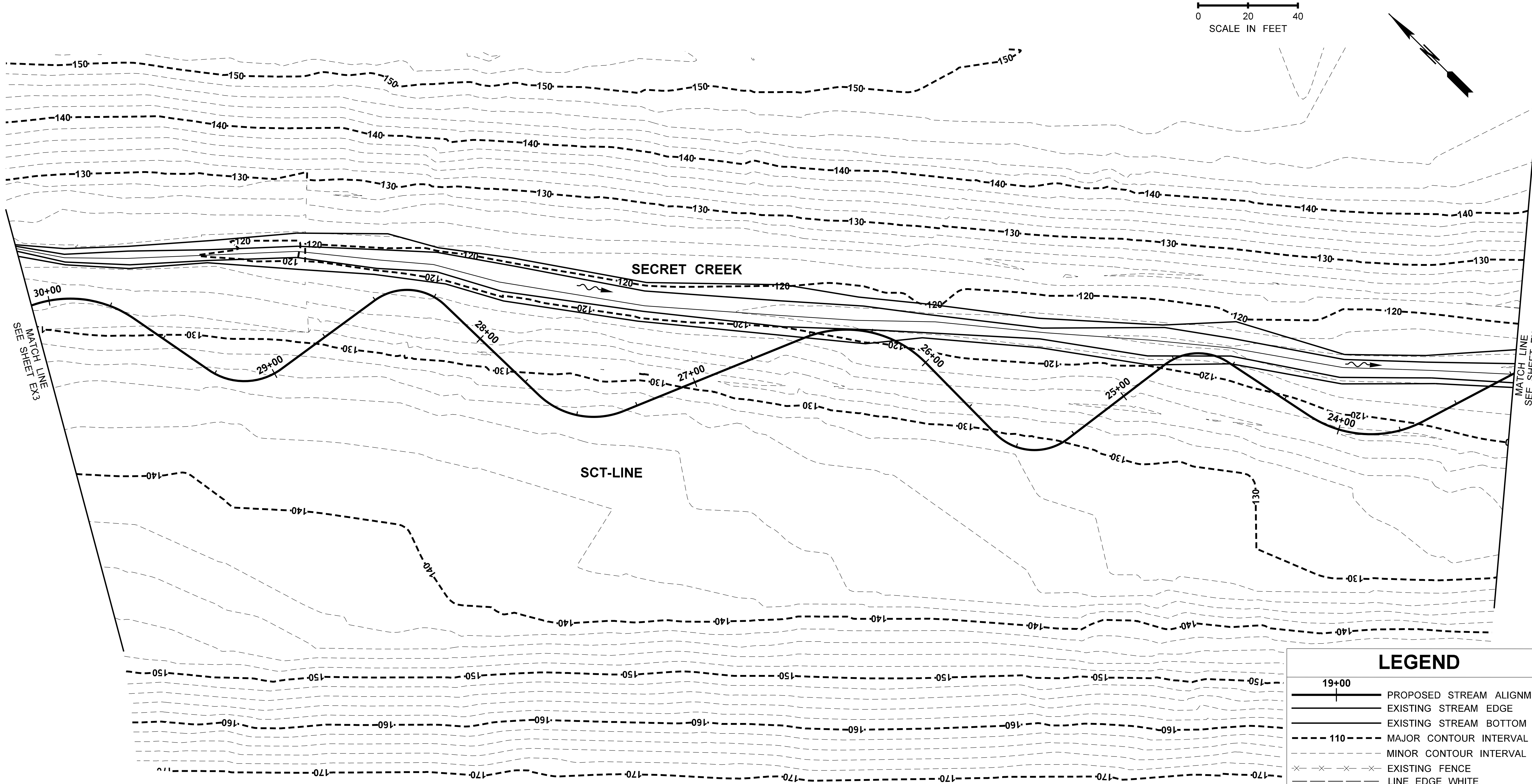
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

EXISTING STREAM

PLAN REF NO EX1

SHEET XX OF XX SHEETS



LEGEND

19+00	PROPOSED STREAM ALIGNMENT
	EXISTING STREAM EDGE
	EXISTING STREAM BOTTOM
110	MAJOR CONTOUR INTERVAL
	MINOR CONTOUR INTERVAL
	EXISTING FENCE
	LINE EDGE WHITE
	EDGE OF ROADWAY
	CURB
	STREAM THALWEG
	EXISTING DITCH BOTTOM
	FLOW DIRECTION
	EXISTING CULVERT
	EXISTING CATCH BASIN
	EXISTING GUARDRAIL

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_EX02.dgn
TIME	12:47:05 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX | DATE

PRELIMINARY

P.E. STAMP BOX | DATE

Washington State Department of Transportation

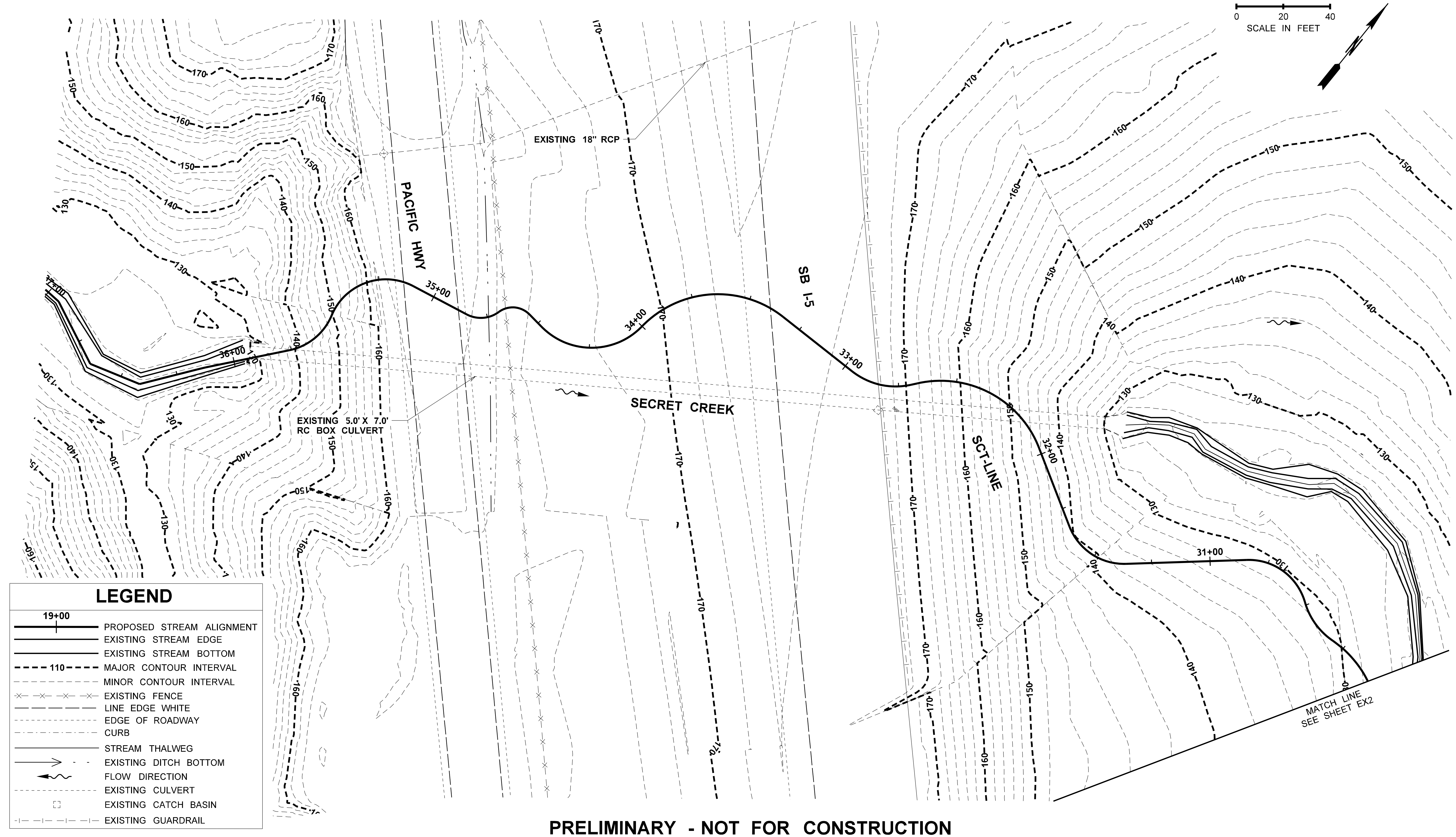
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK FISH PASSAGE

EXISTING STREAM

PLAN REF NO EX2

SHEET XX OF XX SHEETS



PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_EX03.dgn			
TIME	12:47:06 PM			
DATE	7/30/2021			
PLOTTED BY	crosisus			
DESIGNED BY				
ENTERED BY	S. CROSIER			
CHECKED BY				
PROJ. ENGR.				
REGIONAL ADM.		REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX — DATE

PRELIMINARY

P.E. STAMP BOX — DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

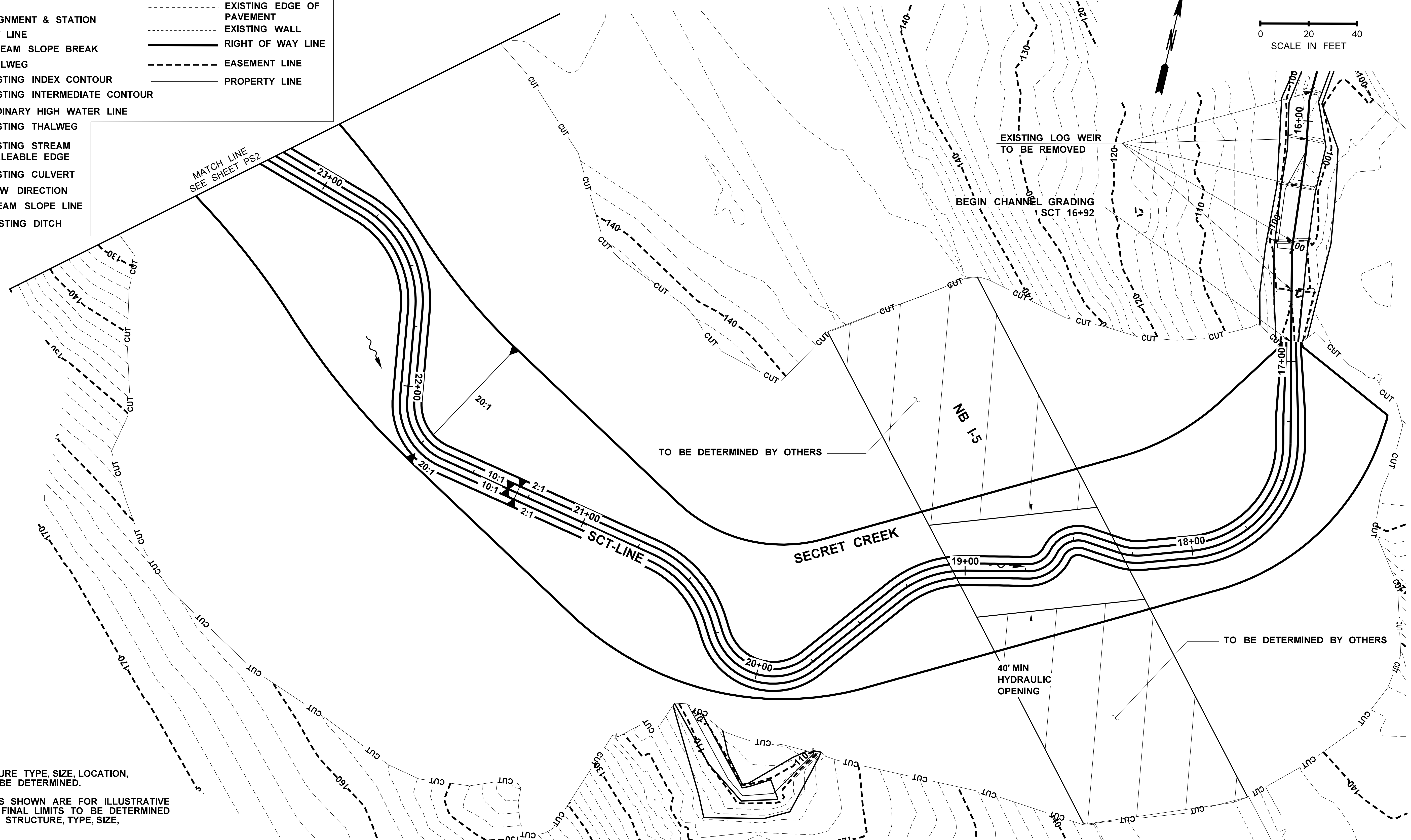
EXISTING STREAM

PLAN REF NO EX3

SHEET XX OF XX SHEETS

LEGEND

- 465+00 — ALIGNMENT & STATION
- CUT — CUT LINE
- STREAM SLOPE BREAK
- THALWEG
- 110 — EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- OHW — ORDINARY HIGH WATER LINE
- EXISTING THALWEG
- EXISTING STREAM SCALEABLE EDGE
- EXISTING CULVERT
- FLOW DIRECTION
- STREAM SLOPE LINE
- EXISTING DITCH
- EXISTING EDGE OF PAVEMENT
- EXISTING WALL
- RIGHT OF WAY LINE
- EASEMENT LINE
- PROPERTY LINE



NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATIVE PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE, AND LOCATION.

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_STR01.dgn			
TIME	12:47:09 PM			
DATE	7/30/2021			
PLOTTED BY	crosisus			
DESIGNED BY				
ENTERED BY	S. CROSIER			
CHECKED BY				
PROJ. ENGR.				
REGIONAL ADM.		REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

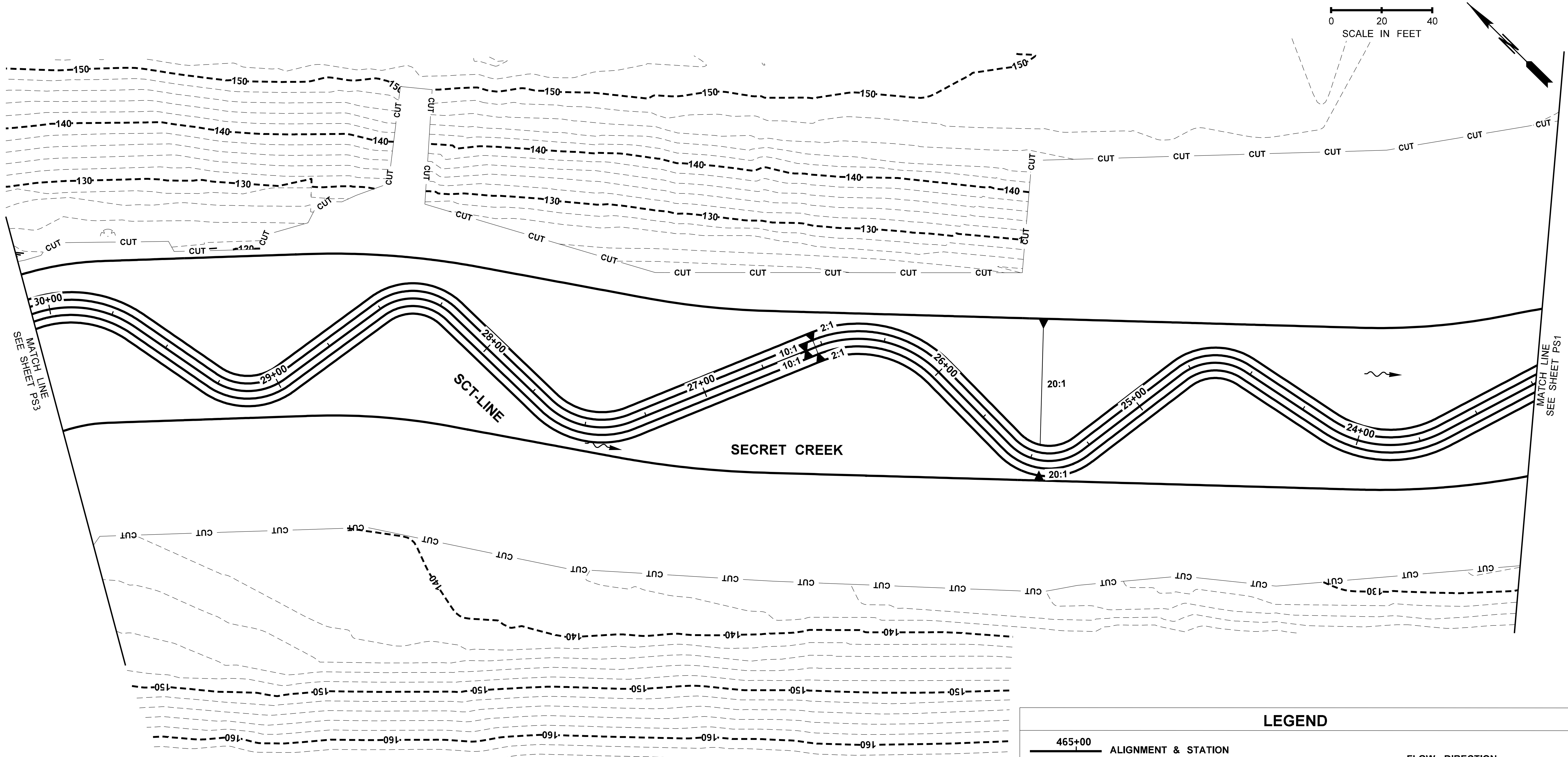
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PLAN

PLAN REF NO PS1

SHEET XX OF XX SHEETS



NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATIVE PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE, AND LOCATION.

LEGEND

465+00	ALIGNMENT & STATION		FLOW DIRECTION
CUT	CUT LINE		STREAM SLOPE LINE
	STREAM SLOPE BREAK		EXISTING EDGE OF PAVEMENT
	THALWEG		EXISTING WALL
110	EXISTING INDEX CONTOUR		EXISTING DITCH
	EXISTING INTERMEDIATE CONTOUR		RIGHT OF WAY LINE
OHW	ORDINARY HIGH WATER LINE		EASEMENT LINE
	EXISTING THALWEG		PROPERTY LINE
	EXISTING STREAM SCALEABLE EDGE		
	EXISTING CULVERT		

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_STR02.dgn
TIME	12:47:18 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

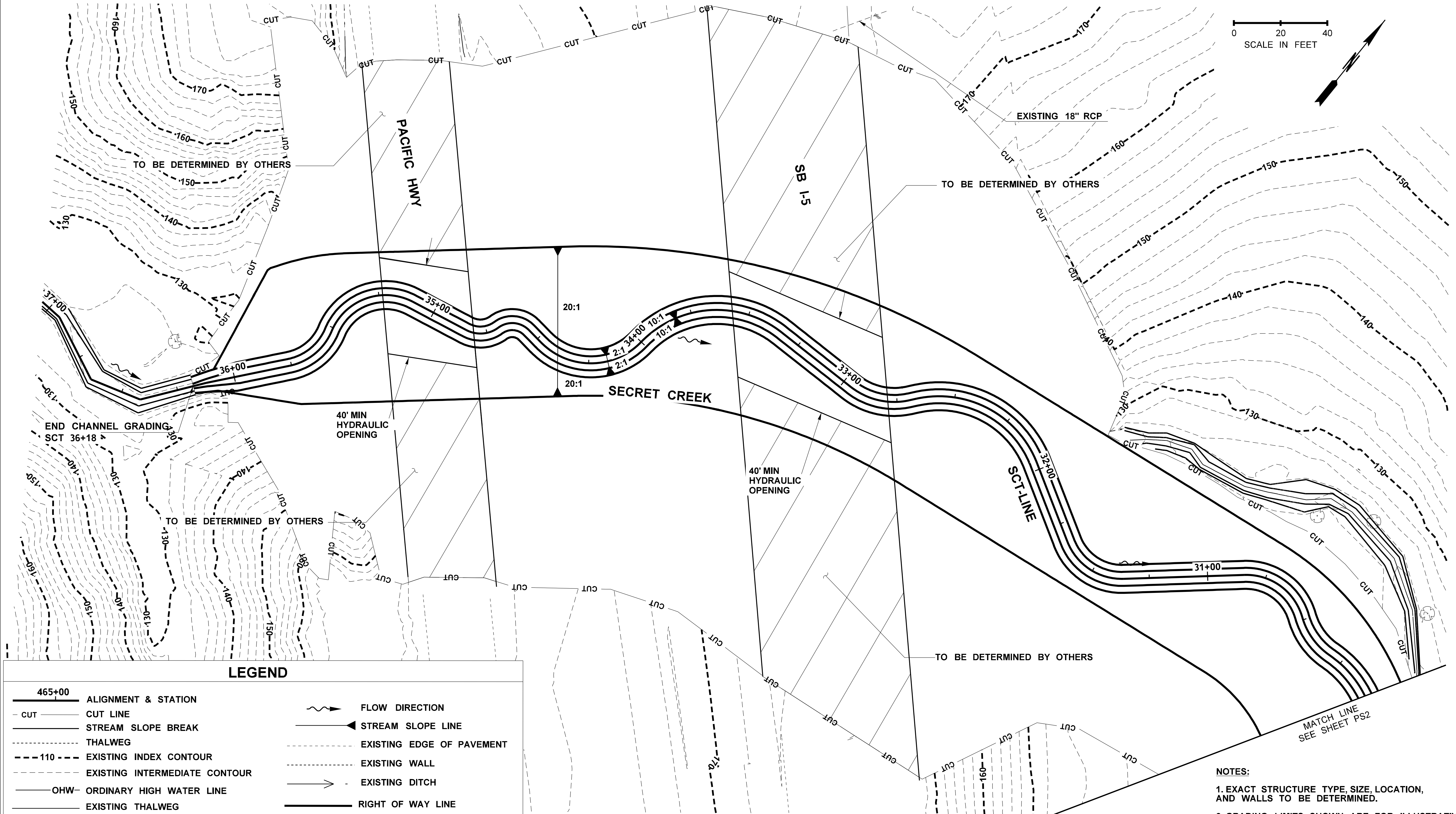
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK FISH PASSAGE

STREAM PLAN

PLAN REF NO PS2

SHEET XX OF XX SHEETS



LEGEND

465+00	ALIGNMENT & STATION
CUT	CUT LINE
	STREAM SLOPE BREAK
	THALWEG
110	EXISTING INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
OHW	ORDINARY HIGH WATER LINE
	EXISTING THALWEG
	EXISTING STREAM SCALEABLE EDGE
	EXISTING CULVERT
	FLOW DIRECTION
	STREAM SLOPE LINE
	EXISTING EDGE OF PAVEMENT
	EXISTING WALL
	EXISTING DITCH
	RIGHT OF WAY LINE
	EASEMENT LINE
	PROPERTY LINE

PRELIMINARY - NOT FOR CONSTRUCTION

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.
2. GRADING LIMITS SHOWN ARE FOR ILLUSTRATIVE PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE, AND LOCATION.

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PS_STR03.dgn
TIME	12:47:21 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX | DATE

PRELIMINARY

P.E. STAMP BOX | DATE

Washington State Department of Transportation

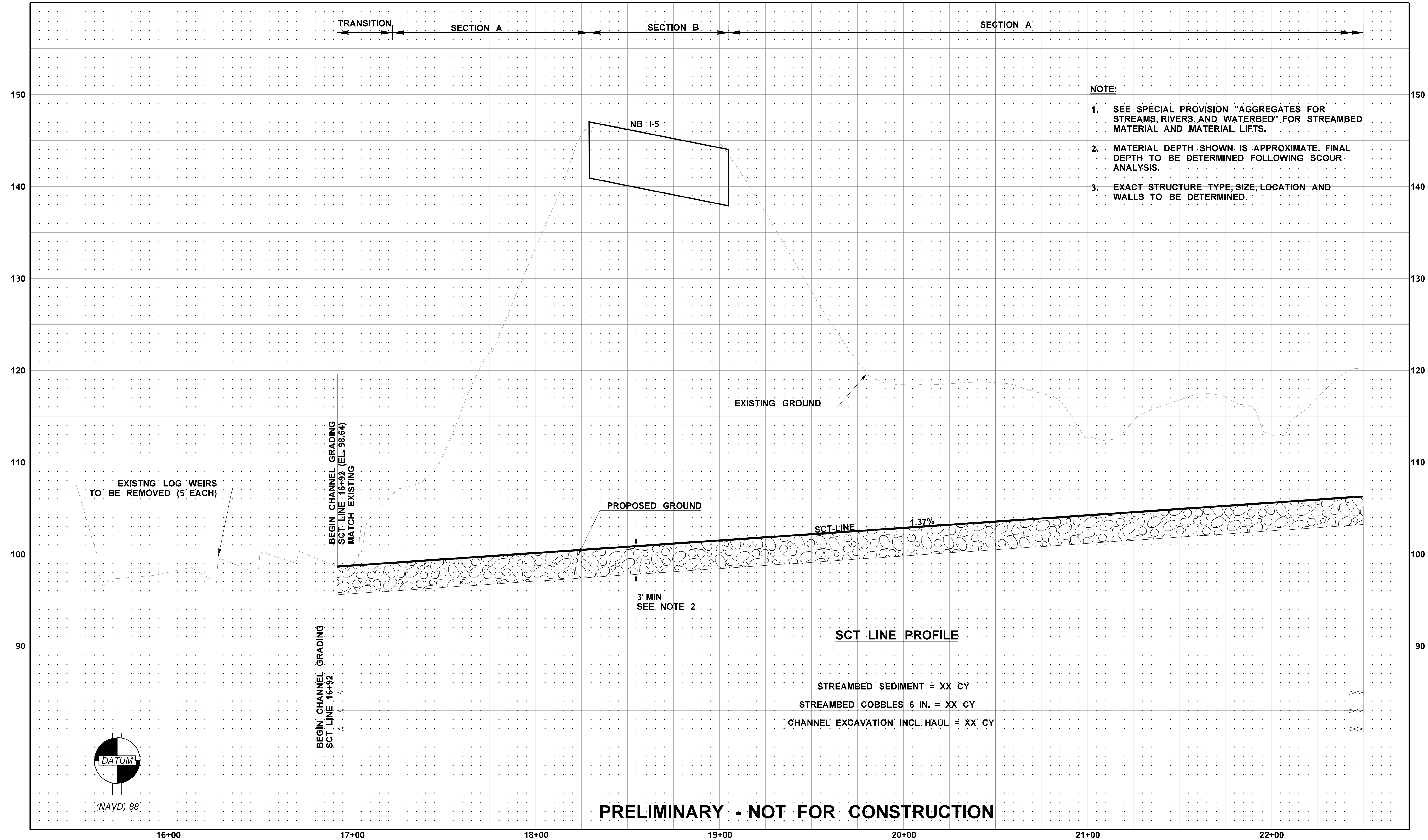
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK FISH PASSAGE

STREAM PLAN

PLAN REF NO PS3

SHEET XX OF XX SHEETS



NOTE:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBED" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. MATERIAL DEPTH SHOWN IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PR_STPR.dgn
TIME	12:47:24 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO. XL5949

P.E. STAMP BOX — DATE

PRELIMINARY

P.E. STAMP BOX — DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

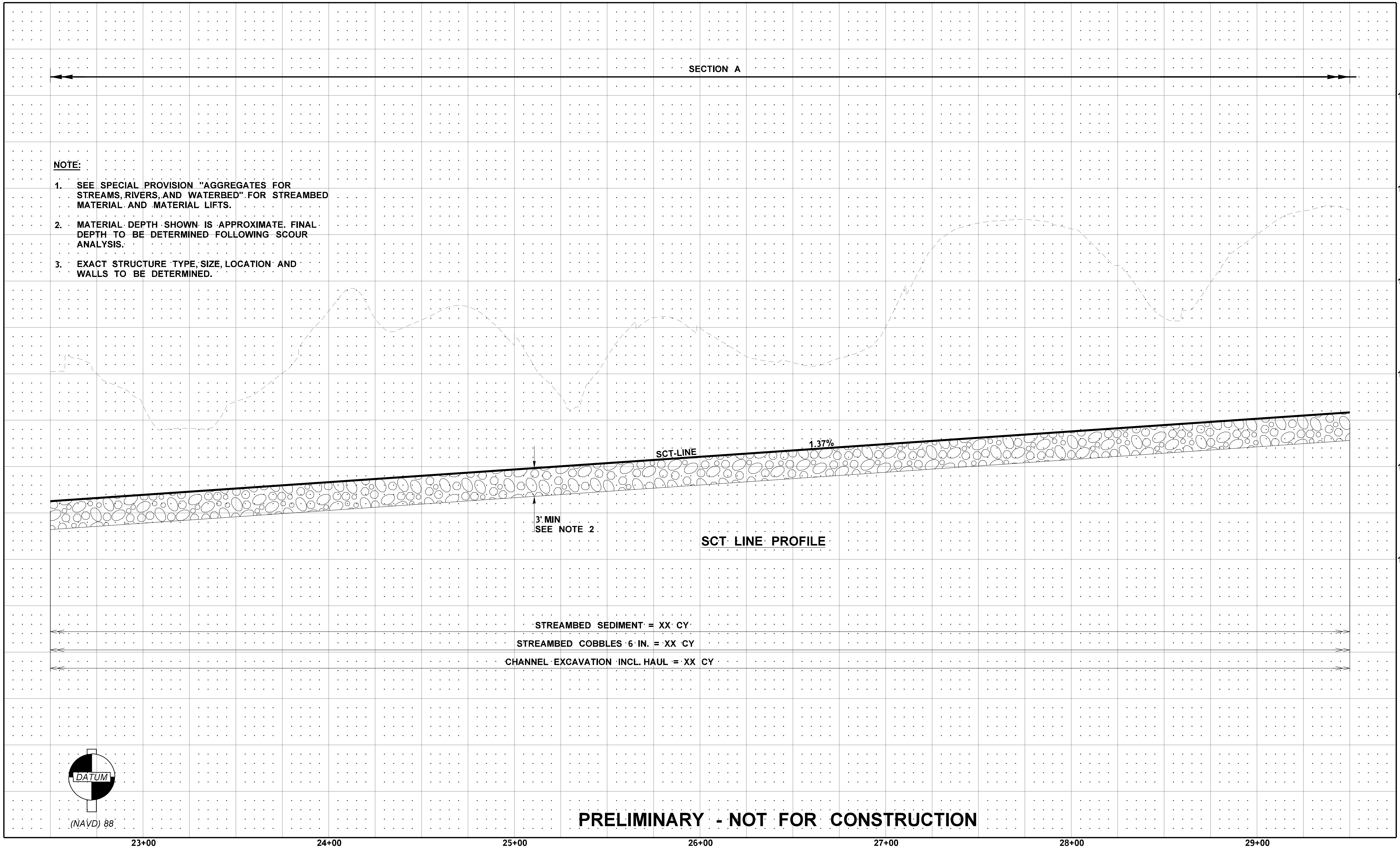
STREAM PROFILE

PLAN REF. NO. STP1

SHEET XX OF XX SHEETS

NOTE:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBED" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. MATERIAL DEPTH SHOWN IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
3. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WALLS TO BE DETERMINED.



PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PR_STPR.dgn
TIME	12:47:25 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO. XL5949

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

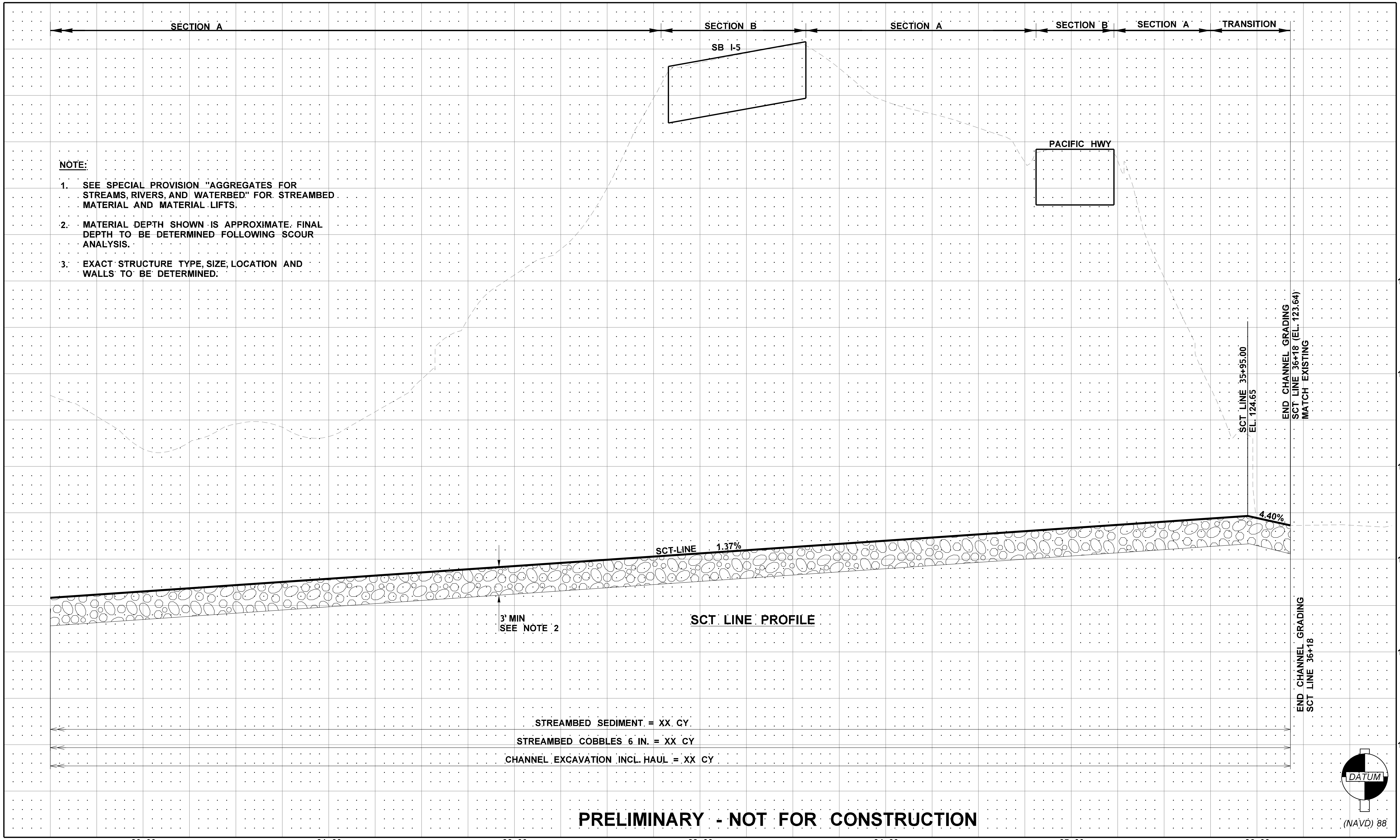
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PROFILE

PLAN REF. NO. STP2

SHEET XX OF XX SHEETS



FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_PR_STPR.dgn
TIME	12:47:25 PM
DATE	7/30/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO. XL5949

P.E. STAMP BOX — DATE

PRELIMINARY

P.E. STAMP BOX — DATE

Washington State Department of Transportation

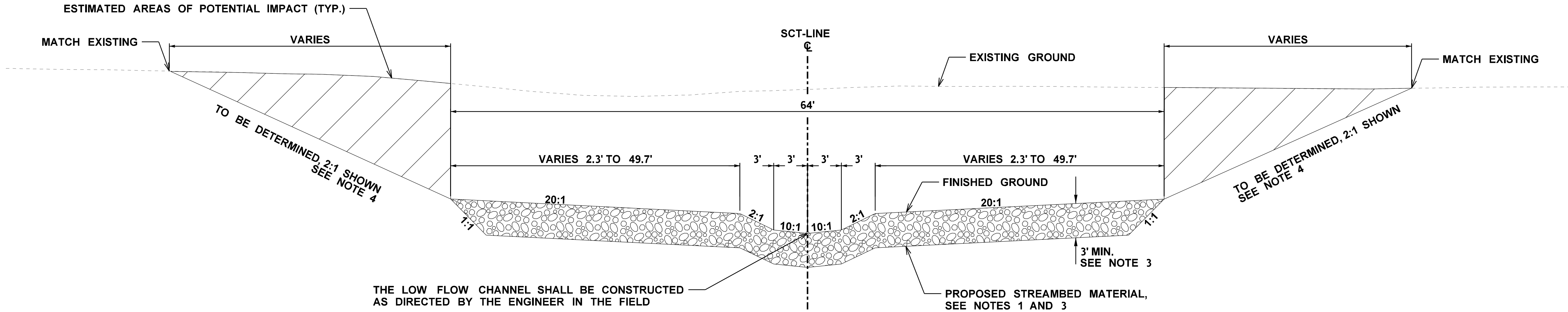
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PROFILE

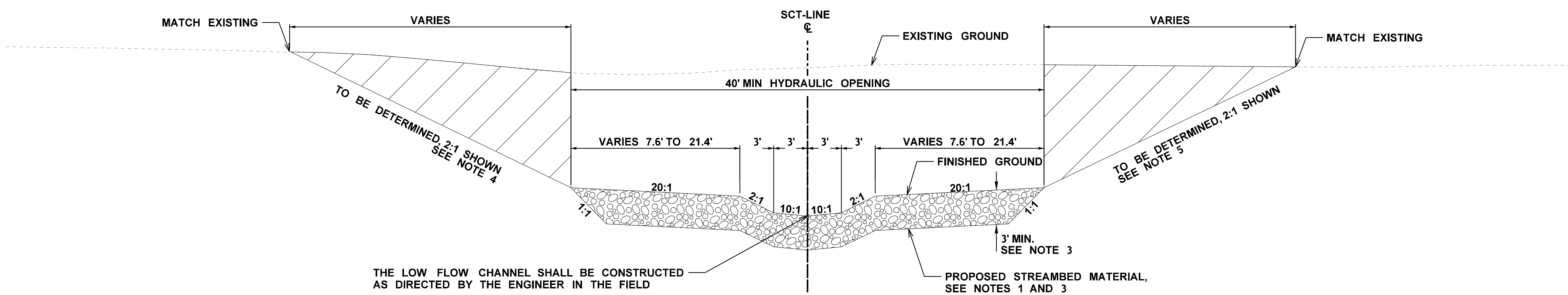
PLAN REF. NO. STP3

SHEET XX OF XX SHEETS



I-5 SECRET CREEK TYPICAL STREAM SECTION A

NOT TO SCALE
STA 17+22 TO STA 18+29
STA 19+05 TO STA 32+79
STA 33+57 TO STA 34+81
STA 35+23 TO STA 35+75



I-5 SECRET CREEK TYPICAL STREAM SECTION B

NOT TO SCALE
STA 18+29 TO STA 19+05
STA 32+79 TO STA 33+57
STA 34+81 TO STA 35+23

NOTE:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. FROM SCT STA 16+92 TO STA 17+22 AND SCT STA 35+75 TO STA 36+18, TAPER SECTION A TO MATCH EXISTING CHANNEL
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
4. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION

PRELIMINARY - NOT FOR CONSTRUCTION

FILE NAME	U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\CADD\DGN\PS&ESheets\SECRET\PS1631127_DE_STRDE.dgn
TIME	2:55:40 PM
DATE	12/1/2021
PLOTTED BY	crosisus
DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO. XL5949

DATE
P.E. STAMP BOX

PRELIMINARY
DATE
P.E. STAMP BOX

Washington State Department of Transportation
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM DETAILS

PLAN REF NO
DE1
SHEET XX OF XX SHEETS

Appendix F

Streambed Material Sizing Calculations

This Page Intentionally Left Blank

Summary - Stream Simulation Streambed Design

Project:	NB I-5 MP 211.5 Secret Creek 990622, SB I-5 MP 211.7 Secret Creek 990623
By:	T. Nabours

Design Gradation:

Location: Proposed Grading

	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.46	0.29	0.10	0.01
in	5.52	3.43	1.15	0.10
mm	140.3	87.1	29.1	2.4

PC Gradation:

Location: Pebble Count 1

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.23	0.14	0.07	0.02
in	2.76	1.66	0.89	0.25
mm	70.1	42.2	22.6	6.4

PC Gradation:

Location: Pebble Count 2

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.39	0.19	0.09	0.03
in	4.72	2.28	1.08	0.36
mm	119.9	57.9	27.4	9.1

PC Gradation:

Location: Pebble Count 3

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.42	0.31	0.15	0.05
in	5.04	3.74	1.85	0.55
mm	128.0	95.0	47.0	14.0

Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	[mm]	Streambed Sediment	Streambed Fines	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914										100	100.0
32.0	813										50	100.0
28.0	711									100		100.0
23.0	584									50		100.0
18.0	457								100			100.0
15.0	381								50			100.0
12.0	305							100				100.0
10.0	254						100	80				100.0
8.0	203					100	80	68				100.0
6.0	152				100	70	68	57				100.0
5.0	127				70	57	57	45				89.5
4.0	102			100	60	43	45	39				86.0
3.0	76.2			80	50	30	38	34				82.5
2.5	63.5	100		70	40	24	32	28				79.0
2.0	50.8	93		60	30	18	25	22				71.0
1.5	38.1	80		50	20	12	18	16				58.7
1.0	25.4	66		30	10	6	12	11				46.4
0.75	19.1	57		10	0	0	5	5				37.1
0.50	12.7	48										31.2
No. 4 =	4.75	35	100									23.0
No. 10 =	2.00	23	85									14.7
No. 40 =	0.425	10	40									6.5
No. 200 =	0.075	5	20									3.3
% per category		65	0	0	35	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		65.0	0.0	0.0	35.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Material Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.047	dimensionless Shields parameter for D50
		uses table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

Limitations:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

	D_{16}	D_{50}	D_{84}	D_{95}
Size (in)	0.095	1.147	3.429	5.524
Size(ft)	0.01	0.10	0.29	0.46
τ_{ci}	0.22	0.46	0.64	0.74
Mobile at Q100?	Yes	Yes	Yes	Yes

**** Use average channel shear stress throughout proposed channel

	Recurrence Interval	2-YR	10-YR	25-YR	50-YR	100-YR	500-YR
	Flow (cfs)	73	139	172	218	278	318
	Shear Stress (lb/ft^2)	0.95	1.25	1.34	1.44	1.54	1.56
τci	1.30	No Motion	No Motion	Motion	Motion	Motion	Motion
	1.25	No Motion	No Motion	Motion	Motion	Motion	Motion
	1.20	No Motion	Motion	Motion	Motion	Motion	Motion
	1.13	No Motion	Motion	Motion	Motion	Motion	Motion
	1.05	No Motion	Motion	Motion	Motion	Motion	Motion
	1.00	No Motion	Motion	Motion	Motion	Motion	Motion
	0.93	Motion	Motion	Motion	Motion	Motion	Motion
	0.88	Motion	Motion	Motion	Motion	Motion	Motion
	0.83	Motion	Motion	Motion	Motion	Motion	Motion
	0.76	Motion	Motion	Motion	Motion	Motion	Motion
	0.72	Motion	Motion	Motion	Motion	Motion	Motion
	0.67	Motion	Motion	Motion	Motion	Motion	Motion
	0.61	Motion	Motion	Motion	Motion	Motion	Motion
	0.58	Motion	Motion	Motion	Motion	Motion	Motion
	0.54	Motion	Motion	Motion	Motion	Motion	Motion
	0.50	Motion	Motion	Motion	Motion	Motion	Motion
	0.44	Motion	Motion	Motion	Motion	Motion	Motion
	0.41	Motion	Motion	Motion	Motion	Motion	Motion
	0.36	Motion	Motion	Motion	Motion	Motion	Motion
	0.27	Motion	Motion	Motion	Motion	Motion	Motion
	0.21	Motion	Motion	Motion	Motion	Motion	Motion
	0.13	Motion	Motion	Motion	Motion	Motion	Motion
	0.08	Motion	Motion	Motion	Motion	Motion	Motion

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

This Page Intentionally Left Blank

Appendix G

WDFW Future Projections for Climate-Adapted Culvert Design Printout

This Page Intentionally Left Blank

Future Projections for Climate-Adapted Culvert Design

Project Name:

Stream Name:

Drainage Area: 1,591 ac

Projected mean percent change in bankfull flow:

2040s: 9.4%

2080s: 15.1%

Projected mean percent change in bankfull width:

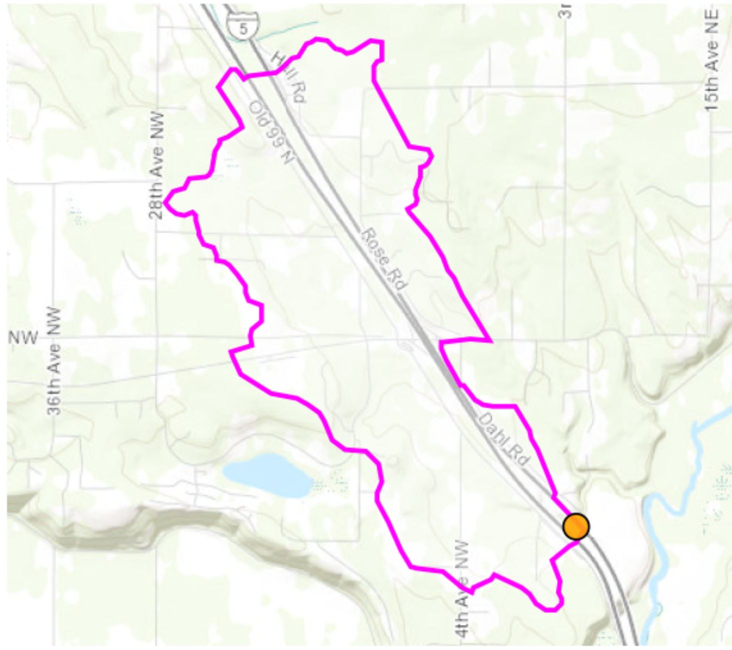
2040s: 4.6%

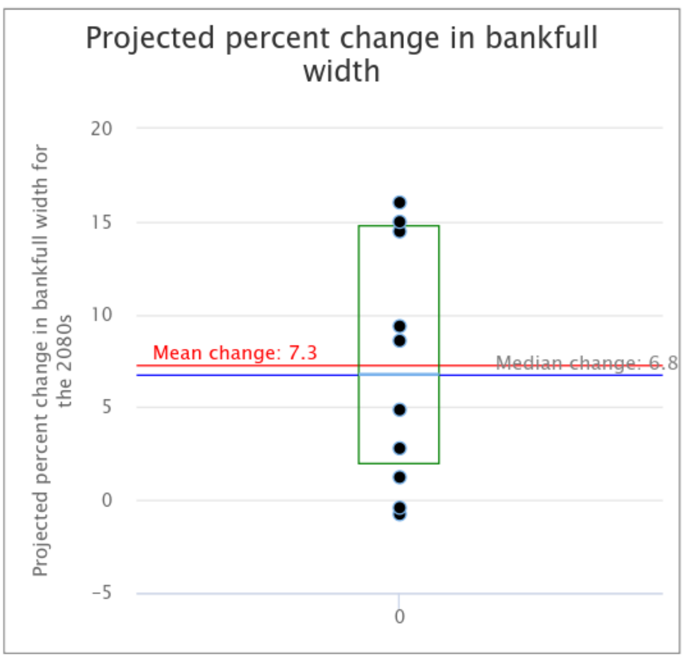
2080s: 7.3%

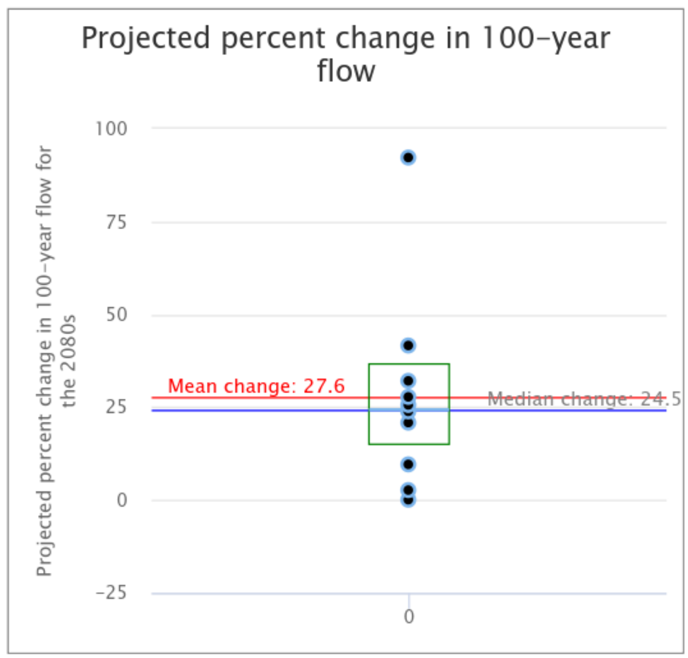
Projected mean percent change in 100-year flood:

2040s: 17.2%

2080s: 27.6%







Black dots are projections from 10 separate models

This Page Intentionally Left Blank